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THESIS

SEDIMENT BUDGET FOR MONTEREY BAY

by

Emmanuel N. Oradiwe

March 1986

Thesis Advisor: E. B. Thornton

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Sediment Budget
For
Monterey Bay

by

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ABSTRACT

A sediment budget analysis based on the principle of mass conservation is performed for Monterey Bay. The various littoral processes in the Bay are evaluated quantitatively. The results indicate that about 2.1×10^6 cubic yards of sand are deposited annually into the Bay, which is treated as a quasi-closed system.

Deposition from cliff erosion, computed from the cliffs profile changes, amounted to 5.6×10^5 cubic yards, and accounted for 27% of the total deposit. River discharges were extrapolated using a power law formula; the total yield was 11.4×10^5 cubic yards, representing 54% of the entire sediment deposition. The potential longshore drift was evaluated using a 18 years spectral wave climatology; its contribution was 4.09×10^5 cubic yards which amounted to 19%. Sediment losses accrued from submarine canyon deposition, sand mining operations, offshore deposition by rip currents and eolian sediment transport to the dunes; these losses amounted to 23.4×10^5 cubic yards and were all estimates taken from previous studies.

The budget deficit signifies an erosion trend along the Bay. The effects of sand mining to coastal erosion are discussed. Recommendations needed to refine the budget analysis and to establish a correlation between the budget deficit and shoreline erosion are presented for further research.

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I. INTRODUCTION

A. OBJECTIVE AND SCOPE

The objective of this work is to establish a sediment budget for the Monterey Bay in which sediment sources and sinks are determined quantitatively. The sediment budget is achieved by a detailed study of the sedimentary environment in the Bay and an analysis of the numerous variables controlling the distribution and accumulation of sediments within the Bay. In outlining the major factors contributing to the sediment budget of the area, the three processes of erosion, transportation and deposition are considered.

The State of California has initiated a "Monterey Bay Erosion Study" to assess the coastal erosion problem and suggest solutions. An objective of this study is to perform a preliminary sediment budget with the knowledge acquired to date, and to make improvement in the calculations of littoral and river transport estimates. The sediment budget can then be used to identify areas of study that need to be emphasized to obtain improved quantitative estimates of the littoral erosion processes.

The determination of sediment budget is necessary for making functional designs of coastal structures and for predicting their influences on adjacent coastal environments. The application of sediment budgets has proven to be an extremely useful approach in evaluating the relative importance of the various sediment sources and sinks within the nearshore zone and in accounting for regions of beach erosion and deposition.

Long-term weather cycles and upland flood control measures have decreased sediment to the river delta. As a result, downdrift coastline is prone to erosion. Acceptable alternatives are artificial beach renourishment or

abandonment of ocean front improvement. To evaluate the cost of a renourishment project, it is necessary to know the net transport out of the affected area in order to know how much sand must be put on the beach and how often the treatment might need repeating. An accurate sediment budget is necessary in order to achieve this goal.

Sediment budgets are effective in plans for harbor dredging, especially where the entrance has shoaling problems. The maintenance dredging costs are directly related to the gross transport past the harbor entrance, and where a permanent sand bypassing system is planned, the capacity of the bypassing plant is related to the gross transport. To achieve this end, one has to consider the sediment budget.

Monterey Bay can be considered as a quasi-closed system and is composed of two littoral cells i.e., a bounded area within which a continuity or budget principle may be applied to the study of beaches and nearshore ocean floor and their changes. Wave studies undertaken by the U.S. Army Corps of Engineers in 1956, indicated that sediments, once entering the Bay, do not leave by any littoral process. Point Pinos and possibly the Monterey submarine canyon appear to be complete barriers to down coast littoral transport (a closed system). The study area and the major credits and debits are shown in Figure 1.1

A further intent of this study is to investigate whether the mining of beach sand significantly contributes to coastal erosion in the Southern Monterey Bay. An accurate budget analysis becomes vital in determining whether the mined portion of the sand is greater or less than the volume available in the southern littoral cell after accounting for other losses.

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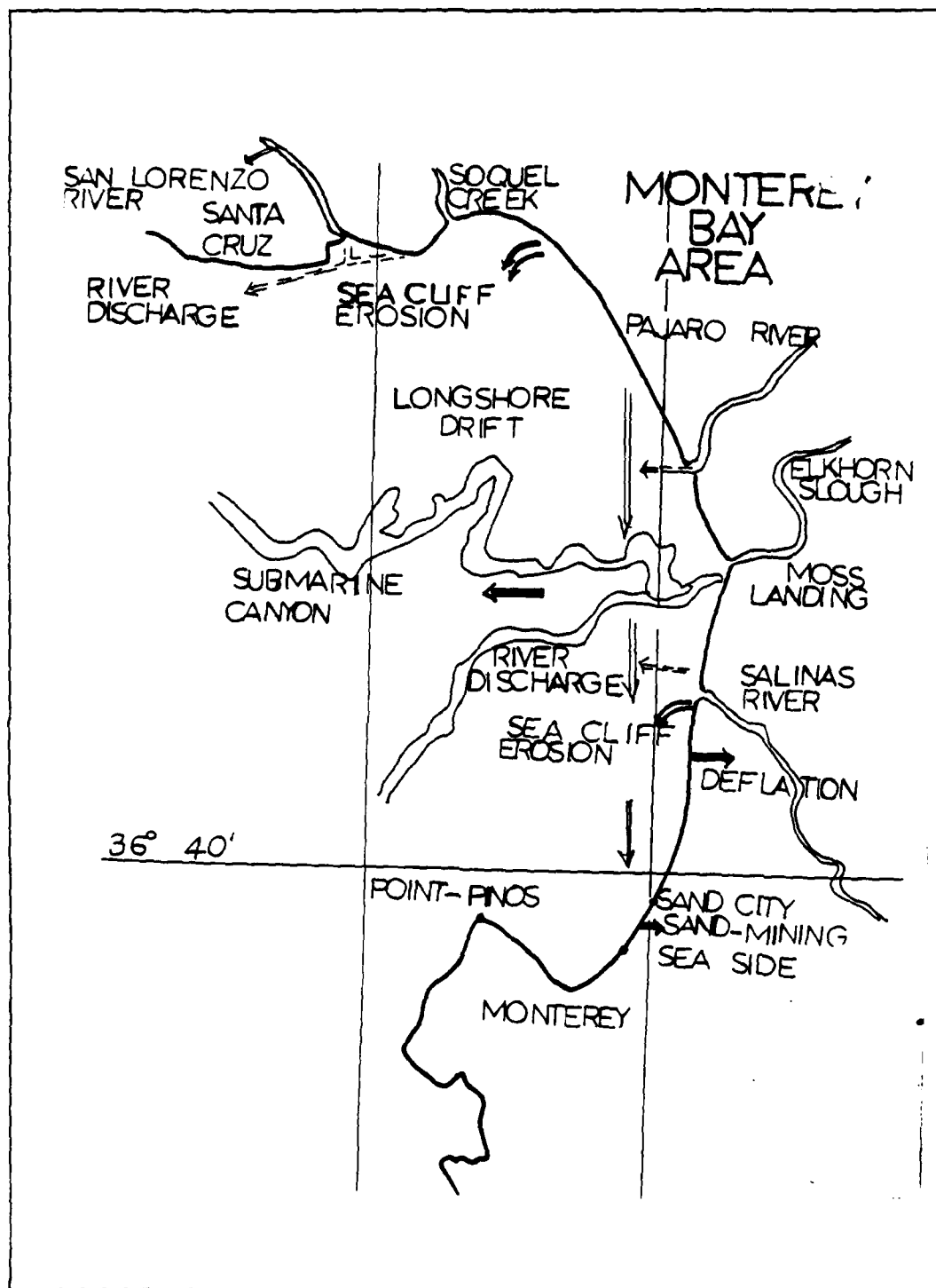
Figure 1.1   Monterey Bay Area.

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B. PREVIOUS STUDIES

Several studies on the Monterey Bay shoreline have been carried out since 1968. Dorman (1968) proposed a sediment budget for the Southern Monterey Bay. His budget was based mainly upon sediment information obtained from field and laboratories. He also carried out a detailed quasi-synoptic sampling to determine the distribution of textural sediment patterns, and a time series study of the beach and surf-zone sand sample obtained from local sand companies. These results were combined with data on Salinas River discharges, the wind and wave regimes and shoreline changes to develop quantitative estimate of sediment gains and losses in the cell. However, he limited his investigation to the sediment of southern half of the Bay, and some of his figures were guesses.

Yancey (1968) placed emphasis on the mineralogical composition of the beach, river and offshore samples in an attempt to determine provenances of the bay sediments. He attributed the nearshore sediments in the southern cell to the Salinas river source. He drew his conclusions on sediment transport by examining the changes in the composition of heavy mineral fraction. His study was mostly on the northern sector of the Bay.

Wolf (1968) studied the clastic sediments of the entire bay in relation to the current patterns of the Bay. Conclusions evident from his work are: (1) Monterey Bay is presently receiving fine-grained clastic material which originate from river sources and erosion of sea cliffs surrounding the bay area, a trend more evident than four decade ago. (2) Deposition of finer-grained sediment on the shelf region due to variation in current directions and velocities so as to prograde the shelf region and in-fill of Soquel canyon. (3) Continental reshuffling of clastic sediment occurs on the shelf region which supply sediment to

the canyon area where they are transported seawards. (4) Bay sediments are under active transport, primarily parallel to isobaths. (5) The overall current pattern on the shelf and in the canyon cannot be correlated with the tides.

Thus, the Monterey Bay region represents an area of nearshore sediment accumulation and dispersion over gently sloping shelves bisected by a large submarine canyon. Sediment supply is from rivers and cliff erosions. The sediments are dispersed by current over the shelves and into the canyon. More intense flow of sediments into the canyon occurs during winter and stormy periods. During summer, sediments are deposited over the shelves and beach areas in response to milder wave climate

Welday (1972) summarized what was known about Southern Monterey Bay coastal environment. His purpose was to determine if continued sand mining was in the best interest of the state, given increasing coastal erosion in the area. Welday's budget was based on Dorman's work with revisions to figures where he thought appropriate. He pointed out that the cell south of the Salinas River delta showed a positive balance which would mean shoreline accretion instead of erosion, and that at least one fifth of the loss by deflation occurs in the area north of the delta. He also showed that about 80 percent of the offshore canyon loss is to the north of the delta area.

Arnal. et. al (1973) calculated a sand budget for Monterey bay. They attempted a systematic approach based on all available informations, including recent works done by the Moss landing marine laboratory. They calculated sediment yield from stream gages and precipitation data. Their results showed that nearly $2.0x10^6$ cubic yards of sand are deposited annually within Monterey Bay. River discharge accounts for 60%, coastal erosion 25%, and littoral drift 15%.

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Finally, Porter.et.al (1979) by examining the textural characteristics of the sediments, determined that the dunes were the major sources of littoral sand in the Southern Monterey Bay, and that the Salinas River contributed an insignificant amount of sand to the southern beaches presumably because most of its sand either move north or is lost to the canyon.

One significant result from these studies is the existence of budget deficit for the Monterey Bay, an indication that the shorelines are continuously undergoing erosion. Although their approaches are similar, the resultant transport estimates differ greatly as shown in Table 1. These differences in transport estimates can be attributed mainly to short time duration of the data base used to make the estimates. Moreover, many assumptions were required in making the estimates which have not been empirically justified.

C. CHARACTERISTICS OF THE STUDY AREA

1. Location and Physiography

Monterey Bay, located about 70 miles south of San Francisco (Figure 1.2), is a wide, westward opening, semi-circular embayment, shaped somewhat like a reverse 'C', with the axis of symmetry coincident with the east-west axis of Monterey submarine canyon. The Bay which is California's second largest, is 12 miles in the east-west direction and 25 miles wide in the North-South direction (Yancey, 1968). For the purpose of this study, the Bay extends from Santa-Cruz to the north and to Point Pinos to the south. Rocky promontories are located north and south of a curving inner coastline of sandy beach. These prominent headlands of the north and south borders of the bay are composed of granitic rocks and siliceous mud stones which are highly resistant to erosion.

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TABLE 1

SAND BUDGET FOR THE SOUTHERN MONTEREY BAY (ALLAYAUD, 1978)

	DORMAN (1968)	ARNAL (1973)	WELDAY (1972)
CREDITS			
RIVER	250,000	373,000	400,000
WIND	30,000	10,000	20,000
EROSION/LONGSHORE DRIFT	200,000	500,000	240,000
TOTAL	480,000	883,000	660,000
DEBITS			
WIND	300,000	50,000	100,000
MINING/ CANYON OFFSHORE	100,000 500,000	250,000 2,040,000	250,000 500,000
TOTAL	900,000	2,340,000	850,000
TOTAL DEFICIT	420,000	1,457,000	190,000

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2.   Continental Shelf

The continental shelf is relatively narrow within the bay, extending no further than 10 miles from the shore, at a depth of about 350 feet. The shelf area slopes gently seawards and is bisected by the Monterey and Soquel submarine canyons. The shelf has an average gradient of 48 ft/mile over the northern side in contrast to 106 ft/mile over the narrower southern side. The shelf-slope transition is rather abrupt in most places, corresponding to the rim of submarine canyon.

3.   Submarine Canyon

In Monterey Bay, the distinctive feature of the offshore area is the Monterey submarine canyon. The Canyon, which is the largest in the Western Hemisphere, extends easterly from deep water in the Pacific Ocean and roughly bisects the bay. The canyon which heads to within 300 feet of the shore at Moss Landing harbor is a steeped walled V-shaped canyon with a high channel gradient maintained through its length, and in depths of less than 500feet. The channel is characterized by large meanders that are entrenched into the late tertiary sedimentary rocks of the bay floor. Soquel Canyon, a branch of the Monterey Canyon, extends northerly and heads in a depth of 240 feet at a point about 6 miles south of Point Soquel.

4.   Shorelines

From Point Santa-Cruz, the northern shoreline of the Monterey Bay extends irregularly eastward about 8.3 miles to the mouth of Aptos Creek. From Aptos Creek, the shorelines curve southeasterly about 10 miles in a shallow unbroken arc to the mouth of Pajaro River. The north shoreline contains several small pocket beaches that often disappear during the winter storms. The beaches are usually backed by cliffs that easily erode under the attack of waves. From the
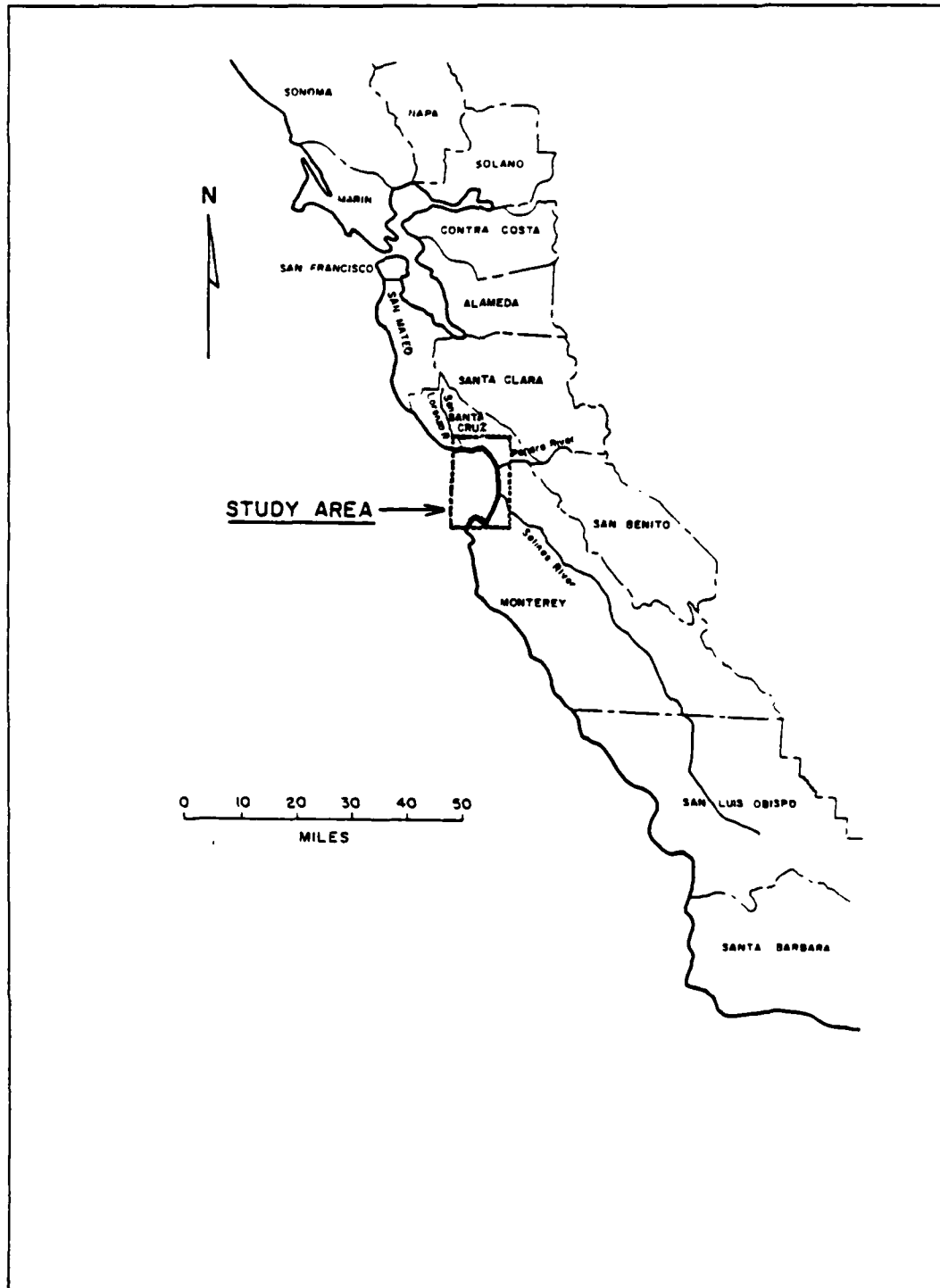
Figure 1.2   The Study Area And Vicinity.

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Pajaro River south to the City of Monterey, the shoreline
consists of wide sandy beaches interrupted only at Moss
Landing. From Monterey to Point Pinos, the shoreline
extends north-westerly about 4 miles and is generally rugged
and rocky. A detailed study of the shoreline, cliffs and
beaches is contained in the section on sea cliff erosion.

5. Drainage Basins

The major drainage basins in the study area that
contribute to the Monterey Bay littoral zones are the San
Lorenzo , the Salinas and the Pajaro basins. These three
basins cover a total drainage area of 5840 square miles.
Two additional minor basins are the Soquel and Aptos Creeks
covering a drainage area of 25 square miles (Yancey, 1968).
The Salinas River, the largest of the three basins, is about
170 square miles long and cover a drainage area of 4300
square miles. The course of this river is generally
northwesterly and the whole basin has a southeasterly trend.
The Pajaro River is about 28 miles long and has a general
westerly course. The Pajaro basins include the Santa-
clara, Benito and the Pajaro valley sub basins; covering an
area of 1400 square miles. The San lorenzo basin includes
the San lorenzo, Aptos and Soquel sub basins, which
generally trend northsoutherly. The basin cover a drainage
area of 165 square miles. The San Lorenzo River flows
southwards and is about 20 miles long.

The different morphologies of these basins modify
the flow characteristics of the rivers. The Salinas and
Pajaro basins have rather low gradients, 3 feet per mile and
15feet per mile respectively. These basins are densely
vegetated and have little alluvial cover. The San Lorenzo
basin has an extremely steep gradient, 51 feet per mile.
Moreover, because of its higher elevation (1000 feet) and
its proximity to the ocean, the San Lorenzo valley receives
abundant rainfall. River channel gradients are important

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characteristics since sediment discharge per unit stream width is proportional to them (Komar, 1976).

6. Coastal Forces

a. Waves

The two types of storm waves that affect the bay are from storms classified as either open ocean or bay wind. An open ocean storm produces swell of large size and long-period with the resulting damage taking the form of shoreline erosion and high wave runup. The bay wind storm is generally a northerly wind storm producing short period waves mostly affecting the Monterey harbor. Thus, the swells are the most significant source of wave energy in the bay and are directly related to shoreline development (Johnson,1956). The deep water waves have significant wave heights varying from 2 feet to more than 30 feet and periods ranging from 4 seconds to 20 seconds or greater. The mean height and period are 4 feet and 13 seconds, respectively. The prevailing direction of wave approach is from the northwest. Winter storm waves with height of 10 feet occasionally approach from the southwest quadrant.

b. Currents

The most important currents transporting the nearshore sediments are the wave-induced longshore or rip currents, which are described in section (F). Other currents that can transport sediments are due to tides, seiches, and offshore oceanic current. Tidal currents can be important particularly around the head of the canyon. The tidal, seiches, and offshore oceanic current velocities are generally one order smaller, leaving wave-induced transport as the principal cause of coastal sediment movement in the bay (Wolf, 1970).

c. Tides

The tides of Monterey Bay exhibit the diurnal inequality typical of most of West coast of North America. The elevation datum for the U.S.West Coast is the Mean Lower Low Water (MLLW). The tidal parameters for Monterey bay at the southern extreme of the bay (NOAA,1982) are:

Mean range	3.5 feet
Diurnal range	5.3 feet
Mean tidal level	2.8 feet (MLLW)
Extreme high water	8.0 feet
Extreme low water	-2.5 feet

d. Winds

Wind records for Monterey Bay are sparse. The prevailing winds are from the west or northwest and have nominal velocities ranging from 4 to 15 miles per hour. Galliher (1932) concluded that the dune orientation in Southern Monterey Bay indicate a northwesterly direction for prevailing wind.
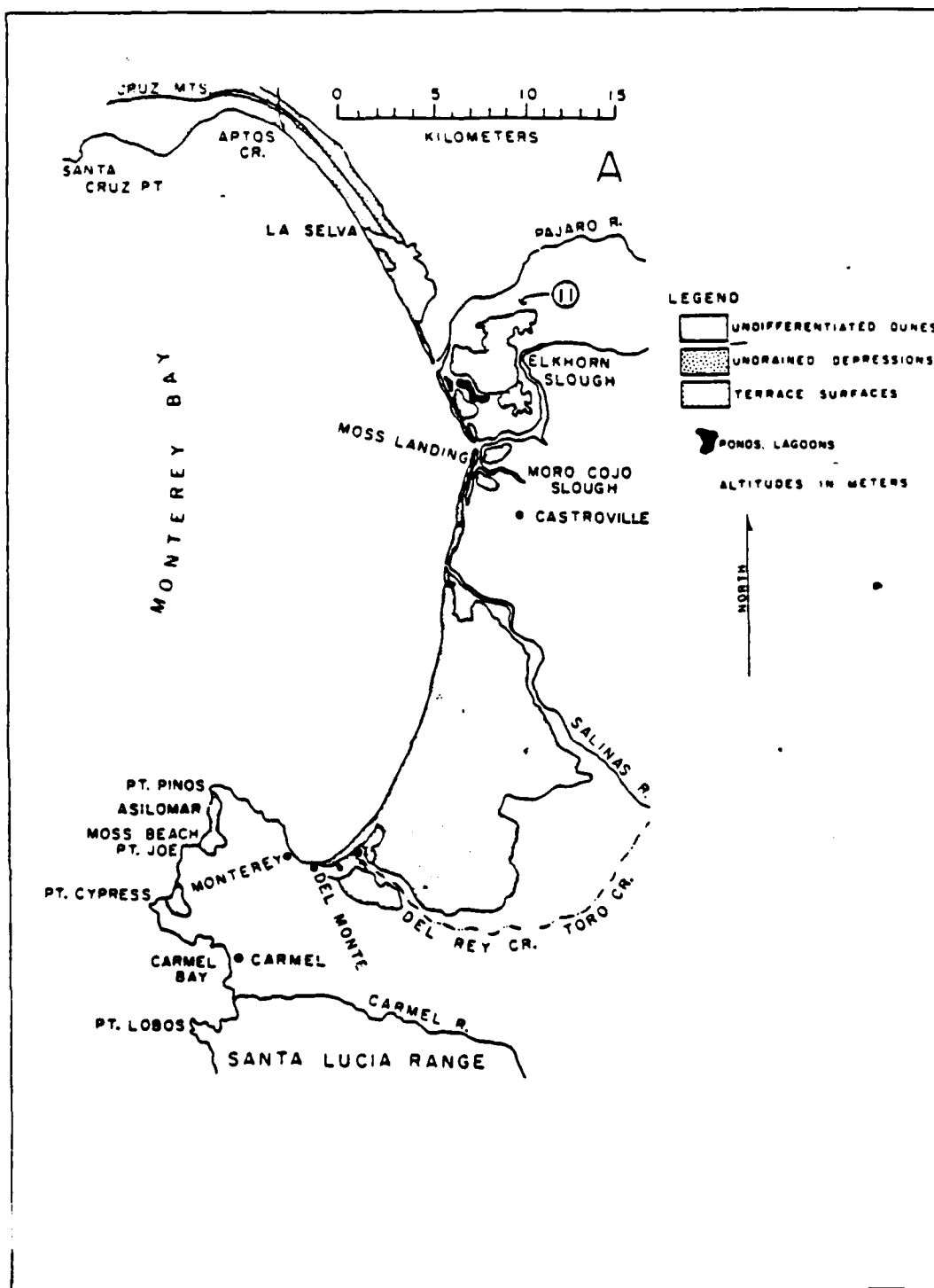
Figure 1.3   Cliffs And Dune Distribution In Monterey Bay.

II. SEDIMENT BUDGET CONSIDERATION

A. GENERAL

The concept of sediment budget is based on conservation of mass and is used to predict changes in the volume of littoral sediments. The budget involves assessing the sedimentary gains (credits) and losses (debits) and equating the difference between them to the net gain or loss (balance of sediments) in a given sedimentary compartment (Bowen and Inman,1966). A sediment gain can produce accreting beaches (deposition) and a loss can produce eroding beaches (erosion).

In Monterey Bay, the major source of sediments are long shore transport into the area from the north, river sediment discharges and cliff erosion; while the major sinks are deposition into the submarine canyon, sand mining operation and losses by wind. A detailed study of the sources and sinks is the focal point of this work.

B. SEDIMENT CELL BOUNDARIES

A sediment budget can best be understood in terms of littoral cells. A littoral cell is defined as a segment of coastline that encompasses a complete cycle of sediment supply, littoral transport and ultimate loss of sediment from the coastal environment.

Habel and Armstrong (1977) separate the California coast into five shore line types. (1) Littoral cells that terminate at submarine canyons. (2) Deltas that are stabilized between head lands. (3)Crescent or crenulate bays. (4) Crenulate spits. (5) Parallel alignments. Monterey Bay shoreline falls entirely into the category of littoral cells that terminate at submarine canyon in the north and is crescent in the south. The bay littoral zone

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is divided into two littoral cells: The Santa-Cruz cell and
the Southern Monterey cell with Monterey Submarine Canyon
separating the two. The Santa-Cruz cell is bounded between
point Santa-Cruz in the north and Monterey Submarine Canyon
in the south; while the Southern Monterey Bay cell starts
from the Monterey Submarine Canyon and ends at Point Pinos.
The two rocky head-lands (Point Santa-Cruz and Point Pinos),
that restrict the long shore movement of sand, portray the
study area as a closed system.

C. METHOD OF APPROACH

Sediment budget is based on sediment removal,
transportation and deposition and the resulting excesses or
deficiencies. Deposition can generally be evaluated by
comparing series of beach profiles. Hence the balance in
the budget of littoral sediment is often known before hand.
The main problem lies in evaluating the credits and debits
such that the net balance fairly agrees with the measured
erosion or deposition. This approach, postulated by Bowen
and Inman (1966) is illustrated with the example shown in
Table 2. With this background, sediment sources and losses
in Monterey Bay are examined, beginning with major sources.

D. SEA CLIFF EROSION

Erosion of sea cliffs, dunes and rocky shorelines
provide a major source of littoral sediments. Cliff erosion
is generally episodic and occurs under attack of storm
waves. It is the severe winter storm waves coincident with
high tides that are responsible for most cliff erosion.
Moreover, winter rain drop often weakens the cliffs and make
them prone to slumping.

The coastal cliff resources in Monterey Bay (Figure
1.3.) are divided broadly into two sectors of Northern and
Southern Monterey Bay. The northern sector is dominated by
10 miles of cliff extending from Point Santa-Cruz to La

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TABLE 2

HYPOTHETICAL EXAMPLE ON SEDIMENT BUDGET

CREDITS

SEA CLIFF EROSION   = X CUBIC YARDS PER YEAR

RIVER DISCHARGES   = Y CUBIC YARDS PER YEAR

LONGSHORE DRIFT   = Z CUBIC YARDS PER YEAR

DEBITS

SUBMARINE CANYON   = N CUBIC YARDS PER YEAR

EOLIAN TRANSPORTATION   = M CUBIC YARDS PER YEAR

SAND MINING OPERATION   = K CUBIC YARDS PER YEAR

OFFSHORE DEPOSITION   = R CUBIC YARDS PER YEAR

BALANCE = (X+Y+Z)-(N+M+K+R) CUBIC YARDS PER YEAR

POSITIVE BALANCE   IMPLIES   ACCRETION

NEGATIVE BALANCE   IMPLIES   EROSION

NIL BALANCE   IMPLIES   STABILITY

Selva Beach, ranging in height between 20 feet to 120 feet. Erosion has caused severe problems because of past development close to the shoreline. As a result, about half the sea cliffs are artificially protected by sea walls, rip raps and revetments. The remaining half is therefore exposed to erosion at an average rate of 13 inches per year (Griggs and Johnson,1979). The immediate upland area between La Selva Beach and Pajaro River consists of old sand dunes approximately 1.8 miles long and 150 feet high (U.S.Army Corps of Engineers,1956). The material exposed in this bluff is primarily weak, poorly consolidated sands that erode quickly when subjected to rain fall and wave action. These flandrian dunes undergo periodic erosion under severe storm at an average rate of 7 inches per year (Griggs,1985).

From Pajaro River south to the City of Monterey, a distance of about 20 miles, the shorelines consist of wide beaches interrupted only at Moss Landing harbor, and by the Salinas River. Between the Pajaro and Salinas Rivers, the beach is backed by dunes averaging 25 feet high and about 600 feet wide. South of the Salinas River the beach is backed by dunes and bluffs overlain by dune sand ranging in elevation from 80 feet to 110 feet and between 600 feet to 3000 feet wide. From Monterey to Point Pinos, the shoreline extends northwesterly about 4 miles and is generally rocky with only short stretches of sand beach. The westward edge of the central and southern bay consist of 15 miles of sea cliff backed by Flandrian dune belt extending from La Selva Beach to Delmonte Beach.

From field observations by Griggs (1985) and others carried out at Fort Ord, it was observed that the coastline in Southern Monterey Bay is seriously eroding. Annual erosion rates from Marina to Sand City range from 2.5 feet to over 10 feet and decrease to zero at Monterey municipal wharf. Cliff erosion at Fort Ord is the most severe despite

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protective measures being taken by the military. Erosion at
Fort Ord is dramatically episodic and is most extreme after
winter storms have removed the protective beaches. Erosion
along several locations in Sand City area indicates average
recession rate of 4-10 feet per year (Griggs,1985).

1. Rate of Cliff Recession

The volume of littoral sediments introduced from
cliff erosion depends on the cliff recession rate, the
height of the cliff and the length of the eroded area. The
causes of the rate of cliff recession are complex and
dependent upon a number of factors which include the
incident wave energy the degree of induration (hardness) of
the material(physical/chemical) composing the cliff, the
degree of natural/man-made protection, ground water seepage
that leads to slumping owing to water saturation, and the
rate at which debris can be removed longshore or to
offshore. A fundamental relation of cliff erosion by waves
can be expressed as follows.

$$X = X(fw, fr, t) \qquad (2.1)$$

where

X = Erodable distance

fw = Impinging force of the wave which depends on wave
height, water level (tide), shallow water bottom and beach
topography.

fr = Resisting forces of cliff material

t = duration of waves

Erosion occurs if and only if (fw >fr) i.e., the impinging
force of the wave is greater than the resisting force of
cliff material. By physical intuition and dimensional
consideration the following equation was suggested by Komar
(1978).

and

H = Height of wave at base of cliff.

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$$fw = A \, \rho \, g \, H \tag{2.2}$$

$$fr = B \, Sc \tag{2.3}$$

Sc = Compressive strength of cliff material
A,B = Non-dimensional constants
ρ = Density of water
g = gravity constant

The cliff recession rate is given by

$$dx/dt = K(\ln A/B + \ln \rho gH/Sc) \tag{2.4}$$

This model relates the rate of wave induced cliff erosion to the two major controlling factors of the wave force at the base of the cliff and the compressive strength of cliff forming material. Since no field studies have actually been carried out to determine the functional form of equation 2.1 and to empirically test the validity of equation 2.4, it is necessary to measure the rate of cliff erosion. The cliff recession rate are measured by photogrammetric technique and are therefore independent of the time of the year, state of tide and other transient and seasonal conditions. Although this method has some deficiencies, it conveniently predicts long term erosion rate in Monterey bay

Many authors have calculated the average rate of cliff erosion in various parts of Monterey bay using the above technique. Table 3 is compiled from various sources giving estimates of average rates of cliff erosion at specific points along Monterey bay by the author.

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TABLE 3

ESTIMATED AVERAGE CLIFF RECESSION RATE IN MONTEREY BAY

	A	NORTHERN MONTEREY BAY
LOCATION	RECESSION RATE FT/YR	SOURCES
PT SANTA CRUZ	1.3	GRIGGS and SAVOY (1985)
TWIN LAKE	2.2	GRIGGS and SAVOY (1985)
OPAL CLIFF	1.1	ANDERSON (1972)
CAPITOLA BEACH	1.5	GRIGGS and SAVOY (1985) ANDERSON (1972)
NEW BRIGHTON	1.3	GRIGGS and SAVOY (1985)
LA SELVA BEACH	3.0	GRIGGS and SAVOY (1985)
PAJARO RIVER	0.6	GRIGGS and SAVOY (1985) DITTMER (1972), U.S. ARMY ENGINEERS (1956)
B		SOUTHERN MONTEREY BAY
ZMUDOSKI BEACH	2.5	GRIGGS and SAVOY (1985) DINGLER. at. al (1985)
EKLHORN SLOUGH	1.3	GRIGGS and SAVOY (1985)
MOSS LANDING	3.0	ARNAL. et. al (1973)
MONTEREY DUNE	1.8	GRIGGS and SAVOY (1985) U.S. ARMY ENGINEERS (1956)
SALINAS RIVER	1.3	GRIGGS and SAVOY (1985) ARNAL. et. al. (1973)
MARINA	4.2	DINGLER. et. al (1985) GRIGGS and SAVOY (1985)
FORT ORD	6.5	DINGLER. et. al (1985)
SAND CITY	6.3	LIMA and SKLAVIDIS (1985)
PHILLIPS PETRO	2.8	LIMA and SKLAVIDIS (1985)
NPS BEACH LAB	1.9	GRIGGS and SAVOY (1985) LIMA and SKLAVIDIS (1985)
POINT PINOS	0.08	GRIGGS and SAVOY (1985)

2. Volumetric Computation

The rate of cliff recession is estimated from the actual amount of the material supplied to the beach. The total volume, (V), of sediment eroded from the cliff is obtained by multiplying the recession rate, (R) by the average height of the cliff, (H), and length of the cliff, (L).

$$V = R.H.L \hspace{3cm} (2.5)$$

This volume must be corrected for the percentage of the sand size sediment that remain on the beach, where the very fine sands are carried offshore and lost to the beaches. It is assumed that 80 percent of the sediment are sand size. The total volume of sand sediment for the entire bay are presented in Table 4, using the results given in Table 3 and Equation 2.5.

3. Comparisons and Remarks

The cliff erosion calculations are comparable to the results obtained by previous authors. Arnal et al (1973) calculated that the total volume of sand coastal erosion is around $6.0x10^5$ cubic yds per year. The U.S. Army Corps of Engineers (1969) estimated the total volume of sand supplied by cliff erosion in the northern sector to be $1.2x10^5$ cubic yds per year. Dittmer (1972) estimated the total sediment volume contributed by the northern sector was approximately $1.0x10^5$ cubic yds per year. These results, considering their orders of magnitude, portray that sea cliff erosion is a significant source of littoral sediment in the Monterey Bay. It is emphasized that these figures are average values, whereas large year to year variations can occur due to the episodic nature of cliff erosion whereby rapid erosion

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TABLE 4

LITTORAL SEDIMENT YIELD FROM CLIFF EROSION

LOCATION	ERODABLE DISTANCE(FT)	RECESSION RATE(FT/YEAR)	CLIFF HEIGHT REF MLLW (FT)	SEDIMENT YIELD CUBIC YARD/YEAR
1 POINT SANTA CRUZ TO LA SELVA BEACH	26,400	1.3	100	127,111
2 LA SELVA TO PAJARO RIVER	9240	0.6	150	30,800
3 PAJARO RIVER TO SALINAS R.	600	1.7	25	944
4 SALINAS RIVER TO MARINA	15,840	3.2	66	123,904
5 MARINA TO FORT ORD	14,850	4.2	66	152,460
6 FORT ORD TO SAND CITY	16,500	6.5	52	206,555
7 SAND CITY TO PHILLIPS PETRO	6,500	6.3	28	42,466
8 PHILLIPS PETRO NPS BEACH LAB	4,200	2.8	24	10,453
9 NPS BEACH LAB TO WHARF #2	3,500	1.9	19	4,697
TOTAL				669,377

PERCENTAGE OF SAND-SIZE = 80%

TOTAL VOLUME OF SAND SEDIMENT = 559,497 =(5.6x10⁵) cubic yard/year

LITTORAL SEDIMENT IN NORTHERN BAY =(1.3x10⁵)cubic yard per year

LITTORAL SEDIMENT IN SOUTHERN BAY =(4.3x10⁵)cubic yard per year

occurs during large storms. Moreover our dependence on
aerial photographic technique is not at all perfect. Aerial
photogrammetry methods have errors such as scale variation
due to altitude variation of the airplane, and variation in
ground elevation. The author recommends further modeling
efforts be made to provide an improved recession rate.

E. RIVER SEDIMENT DISCHARGE

    1. General

        One of the principal sources of littoral sediment
for most coastal areas are the streams and rivers which can
transport large quantity of sand to the ocean. The
quantity, characteristics and causes of occurrence of
sediment in streams are influenced by environmental factors,
the major ones of which are degree of slope, soil
characteristics, and quantity and intensity of
precipitation.

        The total sediment discharge, or total sediment
load, contains suspended and bed load materials. The
suspended load is composed of fine material that at any
given time is maintained in suspension by the upward
component of turbulent current or that exist in suspension
as a colloid. The coarse sediment that move along or near
the stream bed is referred to as bed load. Clay and silt
particles are carried in suspension and gravel particles
move along or near the stream bed. Sand particles which
form the major component of the sediment may be transported
either as suspended load or as bed load or both.

        There are two approaches to estimating the
sediments supplied to the beach by a river. The first
involves empirical correlation between the sediment supply,
the drainage area of the river basin and the effective
precipitation. The second, which is applied in this work,
is estimating the sand transport from measurement of river
discharge or flow velocity utilizing engineering formulas.

Sediment transport equations attempt to relate the transport rate to measurable river parameters, such as river depth and width, channel slope and flow velocity.

2. Sediment Transportation

The relationships of sediment discharge to the sediments characteristics, drainage basin, and stream flow are complex because of the large number of variables involved. At a cross-section of a stream, the sediment discharge may be considered to depend on depth, width, velocity, energy gradient, temperature and turbulence of the flowing water. Furthermore it may depend on size, density, shape and cohesiveness of particle in the bed at the cross-section and in upstream channel. The geology, topography, soil, sub-soils and vegetal cover of drainage area are among the factors on which the sediment discharge may depend. Obviously, simple and satisfactory mathematical expression for such factors as turbulence, size and shape of sediment particles in the stream bed, and the topography of drainage basin are very difficult to obtain. Some assumptions are necessary to reduce the problem to manageable proportion. Some of these assumptions used by various investigators are as follows. (1) River channel gradient is proportional to sediment discharge per unit width of stream (Komar 1976). (2) Mean velocity, average depth and average shear at cross-section are assumed to be acceptable measures of the actual non-uniform velocities, depths, and shear across the section. (3) Some major variables are assumed to be constant from section to section.

3. Suspended-sediment Discharge

Suspended sediment concentration and particle-size distribution data are determined from samples collected with depth-integrating samplers at one or more verticals across a measuring cross-section. The concentration data are then

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combined with water discharge data to compute suspended-sediment discharge using the methods of the U.S.Geological Survey (U.S.Geological Survey,1982). Data obtained from U.S.Geological survey on the study area relate the suspended sediment discharge with this simple equation.

Suspended sediment discharge =(Mean water discharge)x(Mean concentration)

Sediment samples are generally taken on a daily or every other day basis at gaging stations set up by U.S.Geological Survey. During periods of rapidly changing flow or rapidly changing concentration, samples may be collected more frequently (twice daily or hourly). For periods when no samples were collected, daily loads of suspended sediments were estimated on the basis of water-discharge sediment concentration observed immediately before and after the periods and suspended sediment loads for other periods of similar discharges.

Water discharge records are collected from stream gaging stations. The daily mean discharge is computed from gage heights and then the monthly and yearly discharges are computed from the daily figures. At some stream gaging stations the water discharge is affected by back water from reservoirs,tributary streams and other sources. This is rectified by the use of the slope method(U.S.G.S,1982) The slope or fall is obtained by means of auxiliary gages set up at some distance from the base gage.

4. Bed-load Discharge

Bed-load is sediment that moves by sliding, rolling, or skipping on or very near the stream bed; and is supported mainly by the bed rather than by the turbulence of the flow. In this work, bed-load is considered as particles in transit within 0.25 feet of the bed stream.

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When water moves very slowly over a bed of sand,
none of the sand grains may move.   If velocity near the bed
is slowly increased, a critical velocity will be reached at
which some sand grains occasionally moves along the bed for
short distances and then stop. If the velocity near the bed
is.greater than the critical velocity,   sand grains move
intermittently by rolling, sliding or skipping along the
bed.   The movement is within a very thin layer called the
bed layer a few grain diameter thick.   The grain which thus
move in the bed layer and which are supported mainly by
contact with stream compose the bed-load.   They are
maintained in a dispersed state by the grain to grain
contact.   In general,   the rate of travel of these grains
while in motion and the frequency with which the grain begin
intermittent movement depend on the velocity of flow near
the bed.   Obviously, the particle size of bed sediment and
the difference in density between the   sediment and water
coupled with viscosity of the fluid are also significant
factors that affect bed load discharge.   In this study, the
bed load was computed using the REVISED MODIFIED EINSTEIN
PROCEDURE that was developed by Burkham and Dawdy (1967).

5.   Acquisition of Data

As stated earlier, the major drainage basins into
the Monterey Bay are the San-Lorenzo, Salinas and Pajaro
Rivers covering a total drainage area of 5,840 square miles.
Records collected by the U.S.G.S.   gaging stations were
analyzed to obtain the relevant data necessary for sediment
computation.   These records and method of analysis were made
available by the U.S.G.S.   in Sacramento and Salinas
(personal communication with L.Trujillo and P.Antilla)

Suspended sediment discharge and concentration were
monitored daily at 11 gaging stations and periodically at 22
stations along the shoreline of the bay (U.S.G.S,1982).
Although data collected periodically may represent

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conditions only at the time of observation, such data are useful in establishing seasonal relationships between sediment and stream flow and in predicting long-term sediment discharge characteristic of the river. In addition to the records of suspended sediment discharge, estimates of bed load and total sediment discharge are included for some stations. Computation of monthly bed load discharges are based on the relationship between instantaneous water discharge and corresponding bed load discharge for the station. Values of bed load discharge used in defining this relation are based on the Modified Einstein procedure.

In the study area, the author chose stations where the drainage areas closely approximate those of the basins, and which have sediment records. Thus, for the Salinas River basin, the selected station was Salinas River near Spreckels California with drainage area of 4156 square miles and sediment records from 1970-1979. For the San Lorenzo basin, the selected station was San Lorenzo River at Big Trees, Ca with drainage area of 106 square miles and sediment records from 1973-1982. For the Pajaro River basin, Pajaro River at Chittenden, Ca was chosen with drainage area of 1186 square miles and sediment record covering from 1978-1982.

Although these stations have more than 50 years records, these records were mainly water discharge records which are used later in developing an empirical model to predict sediment discharge. Sediment records were only available for relatively short periods. For the San Lorenzo basin both the suspended and bed-load discharge were recorded on monthly basis for 1973 to 1982. For Salinas River basin, only suspended sediment discharge records were available for the periods of 1970-79 at the selected station; but at San Antonio River near Lockwood Ca, which has similar features as Spreckels, both suspended sediment

and bed-load discharge records were available. With the assistance of the (U.S.G.S) the bed-load discharge at Spreckels was estimated as proportional to the water discharge and suspended sediment discharge. A mean ratio of bed-load over suspended sediment for San Antonio was calculated and the ratio was then applied to records on Spreckels to calculate the bed-load, this is deemed a fairly accurate method available for estimation. For the Pajaro River basin, only water discharge and suspended sediment load are available. Uvas Creek has both suspended and bed load discharge record. Using the data from Uvas Creek, and applying the method used in Salinas, a reasonable estimates of suspended sediment discharge and bed load discharge were obtained.

   6. Empirical Model

An empirical power law relationship between the total sediment discharge and water discharge was assumed

$$Qs = K Q^m \qquad\qquad (2.6)$$

where

Qs = Total sediment discharge (tons)

Q = Water discharge (cubic feet per second)

Taking the log of equation 2.6 gives

$$Log\ Qs = m\log Q + \log K \qquad\qquad (2.7)$$

A typical graphical representation of the relationship is shown in figure 2.1. The coefficients($m, \log K$) for the three rivers are solved as the slope and intercept of the least square linear fit to the plot of $\log(Q, Qs)$ see Table 5.

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Therefore, the total sediment discharge for any of the rivers can be estimated using equation 2.6, given the quantity of water discharge and calculated values of (K) and (m) as empirical constants.

7. Long-term Period Computation

Given the values of (K) and (m) for each river, long term sediment load values were calculated using equation 2.6. Water discharge data (Q) were obtained on monthly basis for 41 years, 1940-1980, for each river from the library of U.S.G.S, Salinas. The yearly total sediment discharges were obtained by summing the monthly values and are listed in Appendices (F,G,H). A log-linear graph of total sediments versus period and total water discharges versus periods were plotted for each river. Typical examples are shown in Figure 2.2 and in Figure 2.3 The rest of the graphs are shown in Appendices (B,C,D,E).

8. Comparisons and Remarks

The results shown in Table 6 were made to improve the estimates of the previous authors. Comparisons of the present estimates with previous ones are in good agreement in the order of magnitude. Close examination of the result of Arnal.et.al (1973), suggests compensating errors were made by over-predicting the Pajaro River yield and underpredicting the San Lorenzo River discharge. (Compare Table 6 and Table 7).

As stated earlier, the Pajaro River has a drainage area of 1400 square miles, but a very low gradient; whereas the San Lorenzo River, with a drainage area of 165 square miles, has a higher gradient than either the Pajaro or Salinas basin. (see appendix A). River channel gradient is an important characteristic, since it is approximately proportional to sediment discharge per unit stream width (Komar,1976). Moreover, the San Lorenzo basin, with its steep and rugged terrain, receives more rainfall than Pajaro

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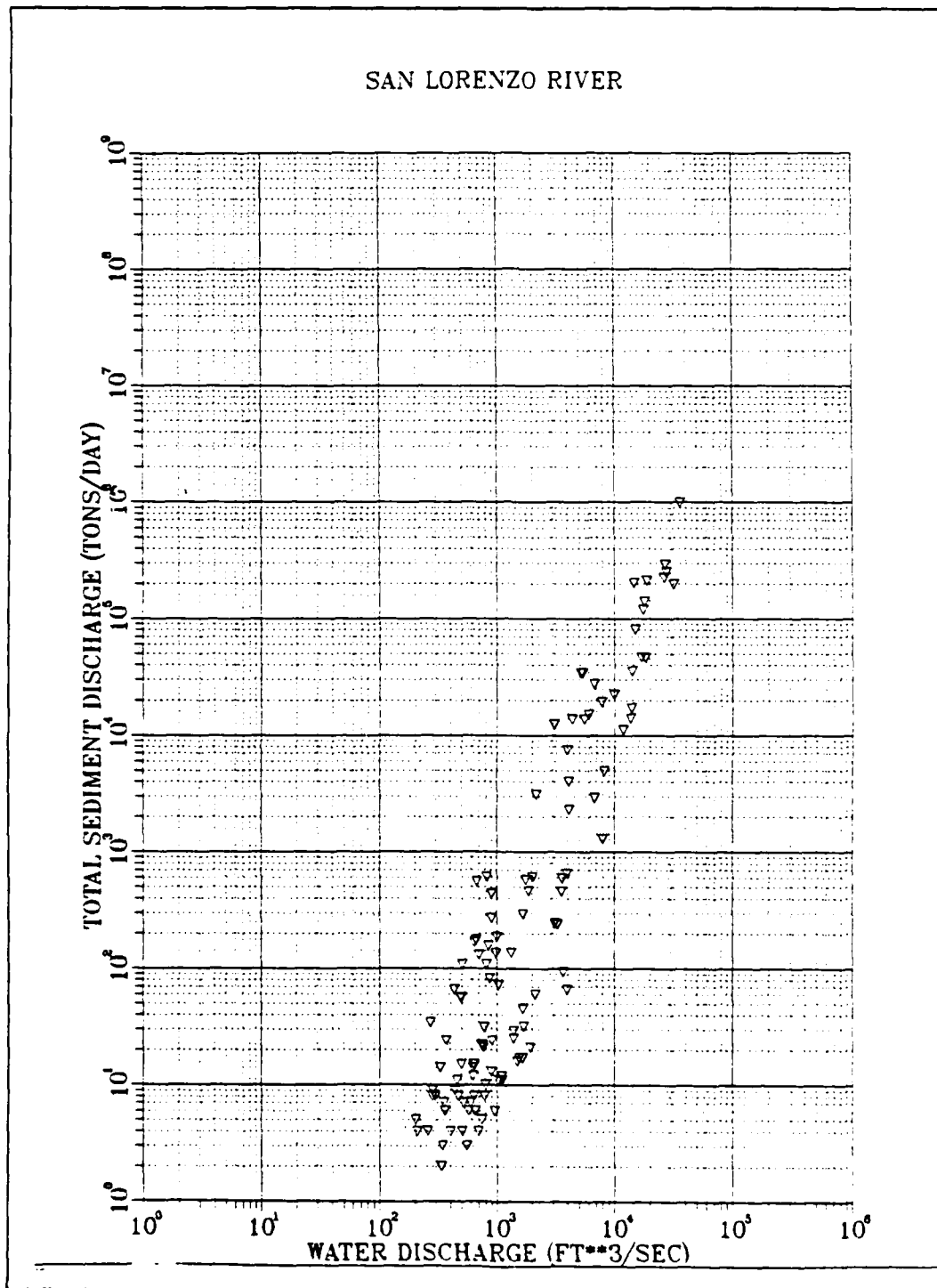
Figure 2.1   Transport Curve For San Lorenzo River.

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                          TABLE 5
        COMPUTED VALUES OF K AND M FOR THE THREE RIVERS

 (1)   SAN LORENZO RIVER
 K = 0.00000489              K* = 0.00000496
 m = 2.3747                  m* = 2.3367
 (2)   SALINAS RIVER
 K = 0.0052                  K* = 0.0044
 m = 1.6369                  m* = 1.6172
 (3)   PAJARO RIVER
 K = 0.00180                 K* = 0.00180
 m = 1.2246                  m* = 1.2219
 Note: (K*) and (m*) are suspended sediment discharge.
```

basin which has low, flat terrain (Dingler, et al 1985), and
hence, maintains a larger volume of run off in the summer
months than either Salinas or Pajaro Rivers (Smith, 1983).
With these striking differences, it is unlikely that Pajaro
River should have more sediment discharge than the San
Lorenzo river; yet Arnal's second result shows that the
Pajaro River discharge is seven times that of the San
Lorenzo.

Dittmer's estimate of 5.3×10^5 cubic yard per year
differs substantially with other results. The reason
attributed to the discrepancy is that Dittmer used only one
year of stream flow data, which is statistically very
unreliable.

One can see that no study was done in Soquel and
Aptos Creeks. This is due to the extreme smallness of their
contribution. Anderson, (1972) in calculating a sediment
budget for the Capitola Beach, estimated the sediment
discharge from the Soquel Creek to be 8,000 cubic yards.
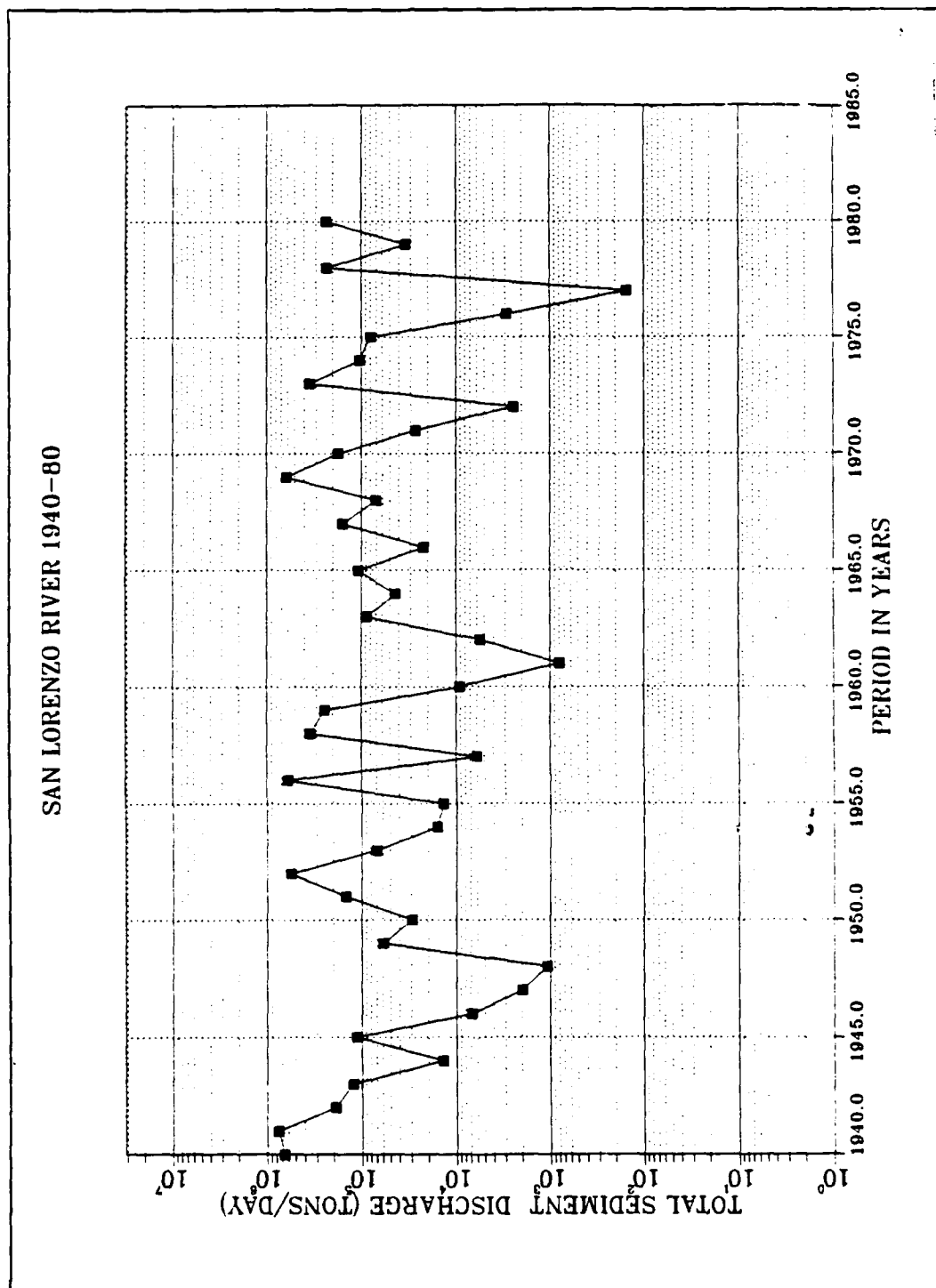
Figure 2.2   Computed Sediment Curve San Lorenzo River.

41
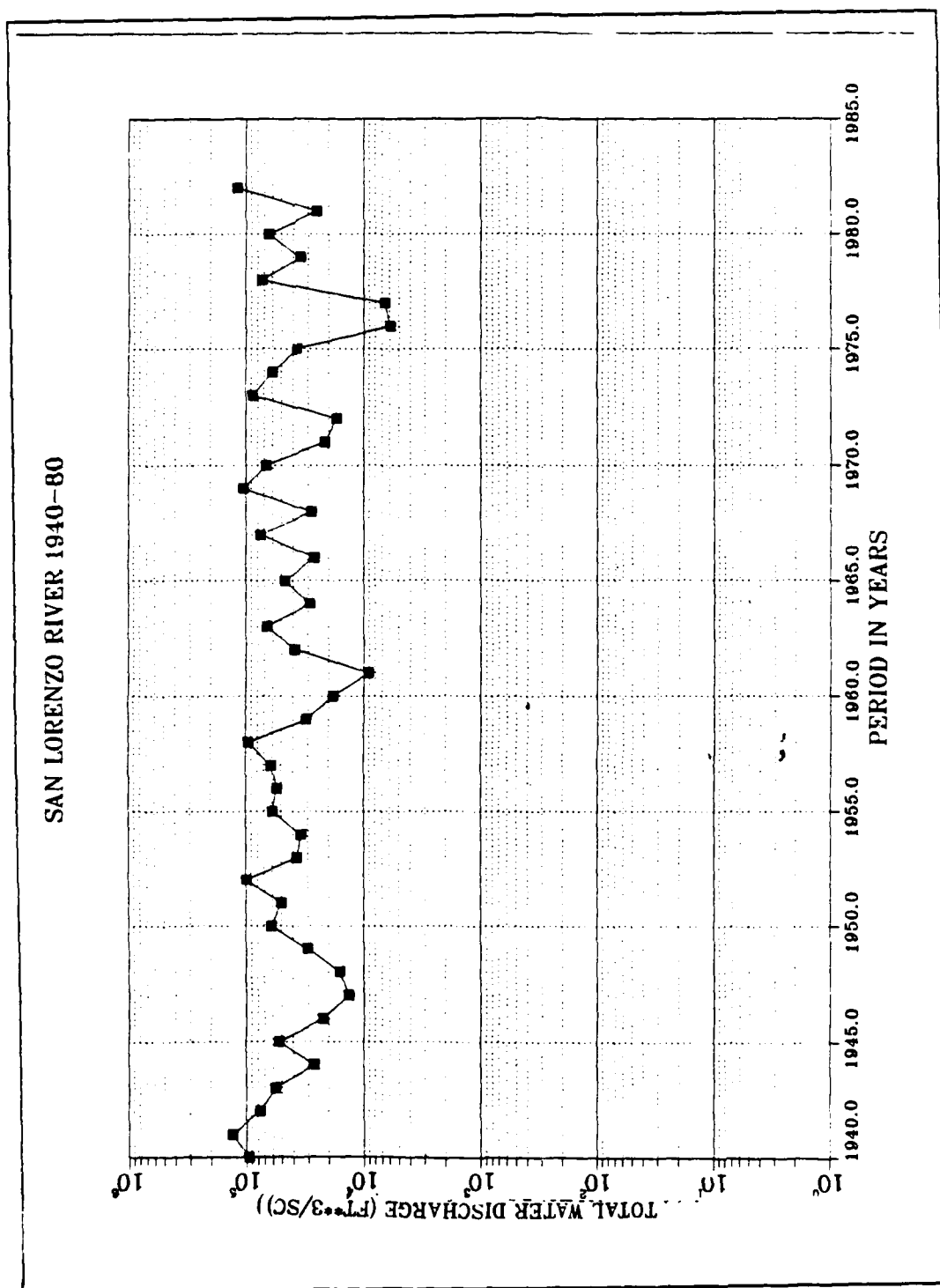
Figure 2.3   Water Discharge Transport Curve San Lorenzo River.

TABLE 6

COMPUTED SEDIMENT DISCHARGE (1940 -1980)

A. AVERAGE ANNUAL TOTAL SEDIMENT DISCHARGE

	TONS	CUBIC YARDS PER YEAR
(1) SALINAS RIVER :	1,230,132	950,171
(2) SAN LORENZO RIVER :	155,864	120,392
(3) PAJARO RIVER :	9,048	6,989
TOTAL :	1,395,045	1,077,552 = 11×10^5

B. AVERAGE ANNUAL SUSPENDED SEDIMENT DISCHARGE

	TONS	CUBIC YARDS PER YEAR
(1) SALINAS RIVER :	824,216	636,636
(2) SAN LORENZO RIVER :	107,958	83,388
(3) PAJARO RIVER :	8,801	6,798
TOTAL :	940,976	726,832 = 7.3×10^5

Arnal. et al (1973) computed the Soquel Creek discharge to be 53,000 cubic yards, and Aptos creek to be 10,000 cubic yards. Their results for Soquel Creek differ significantly, and are so much greater than the deposition from the Pajaro River. To avoid over-estimating the sediment discharges for the two Creeks, the author prudently chose 8,000 cubic yards per year for both creeks, thus making the total river discharges to be 11.2×10^5 cubic yards per year.

TABLE 7

PREVIOUS RIVER SEDIMENT DISCHARGES

AUTHOR/ METHODS	SALINAS RIVER	PAJARO RIVER	SAN LORENZO RIVER	TOTAL SEDIMENT (CU.YDS/YR)
1. ARNAL. et al stream flow	573,773	177,752	233,957	985,478
2. ARNAL. et al sediment/Km^3	631,281	356,550	49,012	1,027,433
3. DITTMER estimates from previous works/ (1971-72) data	299,303	499,274	36,596	835,173
4. DORMAN delta growth	999,855			

9. Discussion

An empirical formula was obtained based on the relatively short data records of river basin discharge. The sediment transport was then calculated using the derived power law formula and the much longer time period (41 years) river flow data.

The REVISED MODIFIED EINSTEIN PROCEDURE (Burkham and Dawdy, 1976) for computing total sediment discharge, which is the preferred method, still has limitations. The procedure has only been tested for sand-size sediments. Tests for conditions in which large amounts of coarse gravels and small boulders are moved as bed load have not been made. These tests are feasible only after good data for bedload movement of coarse sediment are available. Thus the procedure requires experience and judgement. Figures of bedload discharges are estimates, and are subject to revision.

The monthly average water discharge is used instead of daily discharge. Using monthly averages tends to underestimate the result. It is hoped that the U.S. Geological Survey can compute the daily sediment transport values, which would give improvements on the results presented. The present analysis, within limit of the data, still represent a considerable improvement for calculating sediment yield as compared with previous calculations.

F. LONGSHORE SEDIMENT TRANSPORT (LITTORAL DRIFT)

As waves leave deep water where they are formed by ocean storm, they propagate through shoaling water to the shore where they finally break. Associated with this wave breaking is fluid turbulence, and in the case of oblique wave approach, an alongshore (littoral) current is generated, thus as waves break, a part of the energy is expended in turbulence, a part in moving the sediment, and a part into alongshore current.

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In most cases, the refracted waves do not strike the beach head on. There is a small angle (α) between the wave crest and the local beach contour. The angle (α) can be measured also between the wave orthogonal ray and a line taken normal to the beach. Since (α) is rarely precisely zero, there is a small littoral component of motion in the breaker zone and in the swash. In addition to the transport by longshore current, a transport of sediment occurs on the beach face in the swash.

If the wave refraction were such that ($\alpha = 0$), any sand grain in motion will oscillate back-and-forth; along a line normal to the beach and there would be no littoral transport. A non zero value for (α), however provides for littoral transfer. The larger the angle up to roughly 45 degrees, the greater the littoral motion of sand with constant energy density (E). The energy is related to the energy utilized in bottom friction, viscous dissipation and turbulence. The fluid motion responsible for sediment transport is that of waves and current. The waves provide the power to set the sediment in motion and support the sediment either in suspension or as bedload, and the superposed longshore current (weak secondary current) provide an alongshore velocity component that results in the longshore transport of sand. Littoral drift can be considered as a stirring by waves, which induces little net motion, and transport by longshore current which has net motion in the direction parallel to the shore (Thornton,1971). Thus, the longshore current combined with the agitating action of the breaking waves, provide the driving force for sediment movement along the beach.

Given an oblique wave incidence, the uprush of the waves is not precisely up the slope of the beach, but varies to one side or to the other by the angle (α). The back wash, which is controlled by gravity, moves directly down the

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beach slope, and hence does not offset the effect of angle(α)

As a result, a small net lateral transport of both water and sediment take place. This is a littoral transport or drift.

There are two wave-induced current systems in the nearshore zone which dominate the water movement in addition to the to-and-fro motion produced by the waves directly: (1) A cell circulation system of rip currents and (2) Longshore currents produced by an oblique wave approach to the shore line. A schematic of nearshore circulation is shown in Figure 2.4.

1. **Longshore Current**

The mechanism primarily responsible for the wave generated longshore current is the longshore component of excess momentum flux (radiation stress) in oblique shoaling waves (Longuet-Higgins,1970). The radiation stress component in the longshore direction is given by

$$S_{xy} = (EC_g \cos\alpha)(\frac{\sin\alpha}{C})$$
(2.8)

Where
X-axis is normal to the shoreline
Y-axis is parallel to the shoreline.
E = Energy density
Cg = Group velocity
α = Breaking angle
C =phase velocity

Sxy is conserved over straight and parallel bottom contours. prior to wave breaking. The velocity of the longshore current decreases quickly to zero outside the breaker zone. This current is particularly significant in that it is responsible for the net transport of sand or other beach material along the shore.

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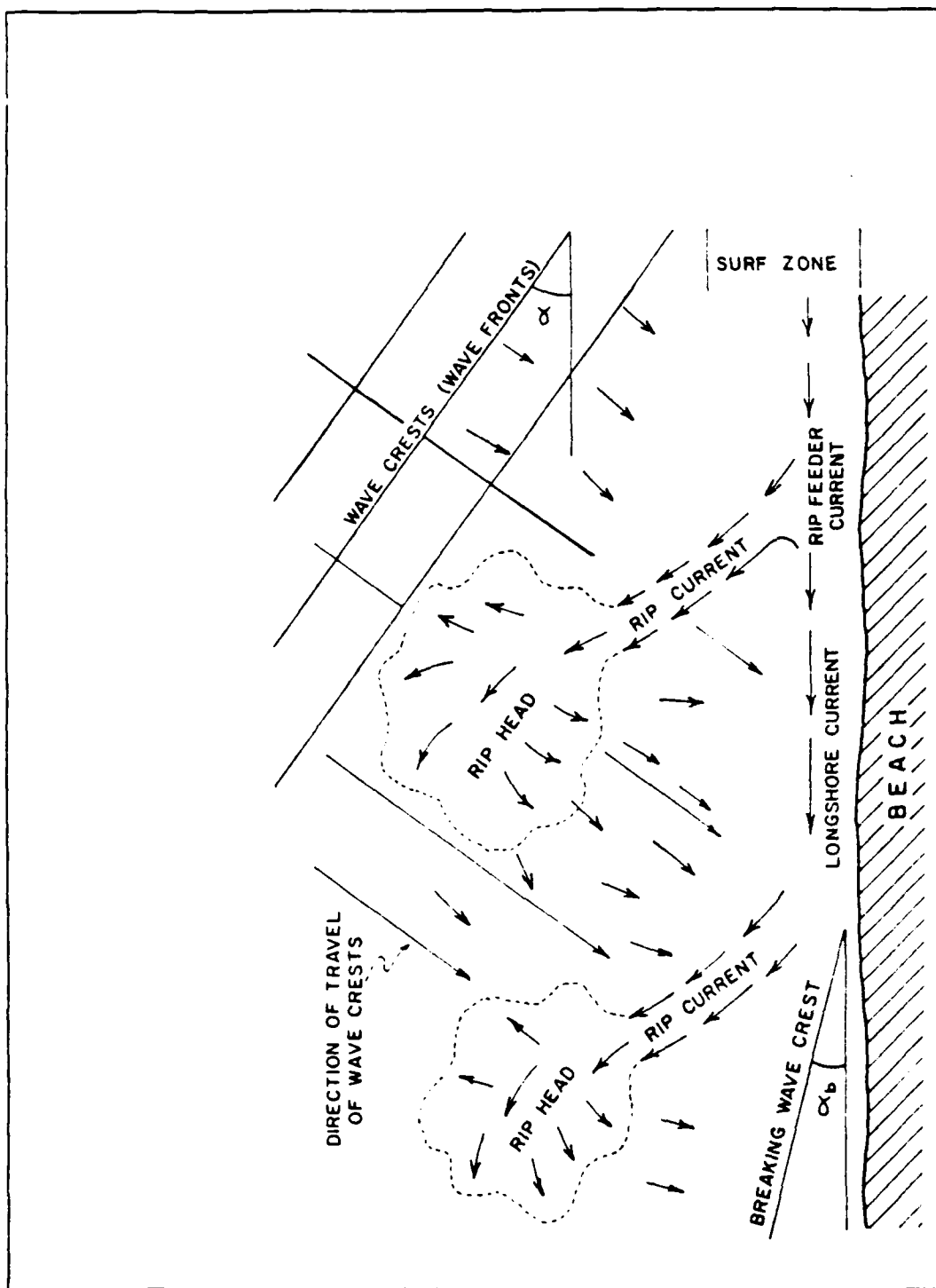
Figure 2.4 Nearshore Circulation.

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2. Rip Currents

Rip currents are strong, narrow currents that flow seawards from the surf zone. They are fed by a system of longshore currents which increase in velocity from zero about mid-way between two adjacent rips and reach a maximum just before turning seawards into the rip. Rip currents depend primarily on the existence of variations in the wave height along the shore. These variations can be produced by wave refraction over varying alongshore bathymetry, edge waves and reflected waves. Bowen and Inman (1969) showed that these variations in wave set-up provide the necessary longshore head of water to drive the feeder longshore currents and produce the rip currents, flowing from the positions of highest breaker height and turning seawards at position of lowest wave height.

Rip currents and longshore currents due to oblique wave approach commonly occur together. Rip currents can redistribute beach sediment by carrying sand offshore and can effect the beach configuration and formation of beach cusps. In this study, the rip currents, coupled with waves conditions are assumed to be responsible for the offshore deposition.

3. Wave Spectra

The wave spectrum $F(f,)$ describes how wave variance is distributed over frequency and direction. An 18 year wave spectra climatology was obtained from the U.S. Navy Fleet Numerical Oceanography Center (FNOC), which was calculated using their Spectral Ocean Wave Model (SOWM). The SOWM is based on wave generation by the Phillips-Miles mechanism and the fully arisen sea described by the Pierson-Moskowitz spectrum. SOWM was used to calculate the wave spectra in the oceans of the Northern hemisphere. The data calculated at a grid point about 100 nautical miles offshore of Monterey Bay was used. The SOWM directional spectrum,

calculated every six hour is described by fifteen frequencies and twelve directions (30 degree directional bands). A complete discussion of the model is given by Pierson (1982)

```
+---------------------------------------------------------------+
|                                                               |
|                          TABLE 8                              |
|           WAVE SPECTRAL FREQUENCIES AND DIRECTIONS USED        |
|                                                               |
|                                                               |
|   FREQUENCIES              PERIODS              DIRECTIONS     |
|   -----------              -------              ---------      |
|                             (sec)               (degrees)     |
|      0.0389                 25.77                             |
|      0.0444                 22.52                 155.5        |
|      0.0500                 20.00                 185.5        |
|      0.0556                 18.02                 215.5        |
|      0.0611                 16.36                 245.5        |
|      0.0667                 15.02                 275.5        |
|      0.0722                 13.85                 305.5        |
|      0.0806                 12.41                             |
|      0.0917                 10.91                             |
|      0.1028                  9.73                             |
|      0.1167                  8.57                             |
|      0.1333                  7.50                             |
|                                                               |
+---------------------------------------------------------------+
```

4. Wave Refraction

As waves advance from deep water towards the shoreline they either spread their energy over a greater length of the shore and consequently decrease in height, or concentrate their energy over a shorter distance and increase in height. On reaching the shoreline, the waves strike the shore at an angle determined by the original

direction of propagation or by the amount of refraction during the shoaling of the waves. Waves approach perpendicular only if the original wave front was parallel to the shoreline and underwent no refraction during shoaling. Most waves do not meet this condition and as a result, provide a component of force parallel to the beach which creates longshore transport of sand. Wave refraction is a predominant factor in determining the direction of longshore drift. Wave refraction analysis is used in determining the distribution of wave energy flux along the shoreline, which enables the calculation of the littoral drift.

The formulation of wave spectra transformation over a shoaling bottom is based on the premise that the wave energy associated with a narrow band of frequency and direction stays within that band during the transformation. Thus the shallow water spectrum can be determined from the deep water spectrum by applying the squares of both the refraction (Kr^2), and the shoaling coefficients (Ks^2) to each frequency component, and multiplying by the Jacobian of the direction function which preserves the transformation. Hence we have:

$$F(h, f, \alpha) = F(f_o, \alpha_o) K_r^2(h, f, \alpha_o) K_s^2(h, f) J$$

(2.9)

$$J = \frac{d(f_o, \alpha_o)}{d(f, \alpha)} = \frac{d\alpha_o}{d\alpha} \quad \text{SINCE} \quad f = f_o$$

The shoaling coefficient is determined from linear wave theory as the ratio of the deep and shallow water group velocities

$$K_s^2(h,f) = \frac{C_g(f)}{C_g(h,f)} \qquad (2.10)$$

As will be seen, the interest here is in total energy integrated over all frequencies and direction and as a consequence, the differentials integrate away and it was not necessary to calculate the Jacobian.

Wave refraction was calculated only for the twelve lower frequencies (0.039 - 0.133) hz and the six central directions from the ocean (from 155 - 305 degrees) of the SOWM spectra (see Table 8.). The higher frequency wind wave components (greater than 0.13 hz) are primarily generated by local winds. It was felt that these components represent local condition at the hindcast location, and were therefore not included. A total of seventy-two (72) refraction coefficients (12 by 6) were calculated for each of the fifteen (15) locations chosen within Monterey Bay (see Figure 2.11.).

The linear refraction program by Dobson (1967) was used to calculate the refraction coefficients and breaking wave angles. The refraction program is run backward from shallow to deep water, starting from points of interest in 4 meter depth. Rays at a particular frequency were sent offshore at one degree increment over the range of possible angles, as shown in example Figure 2.5 - 2.7. The shallow water wave angles (α_s), were specified relative to the local beach contour. The rays were stopped in deep water, and the deep water angle measured. The rays were then returned along the same ray path to calculate the refraction coefficient Kr for the point of interest.

The bathymetry used in the refraction program was obtained from the original NOAA data (6-second latitude-longitude grid). The depth values were screened for errors, and the depths were then projected onto a Modified Universal Transverse Mercator projection. The

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depth data are sparse offshore and dense inshore, requiring interpolation to fill the empty grid points. Piece-wise linear triangulation was used to interpolate to a regular grid of 200 meters, which gives the least amount of distortion due to curve fitting. A 9 point weighted linear averager was then applied to smooth the bathymetry. Further smoothing of the bathymetry is accomplished in the Dobson (1967) refraction program. The curvature of the bottom is calculated in the ray calculations, which is accomplished by fitting a least square quadratic surface to the adjacent depth values. The bathymetry is shown in Figure 2.10.

Average Kr values were calculated by averaging the calculated Kr values falling in each 30 degree band. Averaging was accomplished by integrating Kr versus deep water angle (α_g) over the band and dividing by the 30 degree band. The linear refraction program assumes bottom changes are gradual. This assumption is not always true in Monterey Bay because of the canyon. As a consequence the model sometimes (infrequently) calculates unstable estimates. Therefore, all Kr values exceeding 3 were subjectively discarded. Examples of the calculated refraction coefficients as a function of nearshore angle are shown in Figure 2.8

5. Longshore Sediment Transport Rate

The engineering formula for calculating sediment transport is based on the energy flux method. The energy flux method empirically relates the spatially integrated longshore transport rate (Qs), to the longshore component of wave energy or longshore power by an equation of the form:

$$Q_s = KP \tag{2.11}$$

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where P is dependent on wave frequency and the approach angle, and K is a proportionality factor, depending on waves and sediment parameters. The empirical data for equation 2.11 was obtained from fluorescent tracer studies and impoundment studies as summarize in Figure 2.9.

Various values of K are reported in the literature, given here for MKS units. Dean (1985) determined K to be 1.23 in his study at Santa- Barbara, CA and 0.94 at Rudee inlet, VA. Komar (1977) determined K to be 0.77, and Galvin (1969) found K to be 1.60. Comparing values of K, Dean (1985) found a trend of decreasing K with increasing sediment diameter. The dependence of K on this parameter as well as the effect of beach slope, may be the cause of the observed variations in the values of K. Because of the uncertainties reported in the values of K, it was decided to apply the standard value suggested by the U.S.Army Corps of Engineers (1978), which is the standard procedure; and equation 2.11 becomes:

$$Q_S = 7.5 \times 10^3 P \qquad (2.12)$$

where:

Qs = cubic yards per year

P = ft-lb/sec/linear ft of beach

The longshore power is calculated from the transformed wave spectrum and shallow water wave angles

$$P(f,\alpha) = \rho g F(f,\alpha) C_g(f) \sin\alpha_s(f) \cos\alpha_s(f) \qquad (2.13)$$

The longshore power in equation 2.12 is to be calculated at the breaker line. The

The longshore power was initially calculated at the 4 meter contour using the transformed wave spectra from deep water. The longshore power at 4 meter contour was then transformed to the breaker line by assuming the bottom contours between the 4 meter and the breaker line are straight and parallel. Recalling that the radiation stress (equation 2.8) is conserved over straight and parallel bottom contours outside the breaker line, P at breaking can be written by multiplying the numerator and denominator of equation 2.13 by C(f).

$$P_{L_b} = E(f,\alpha) \frac{C_g(f)}{C_s(f)} \sin \alpha(f) \cos \alpha(f) C_s(f) \qquad (2.14)$$

$$= S_{xy}(f) C_b'(f)$$

Where the energy at each frequency and direction is given by

$$E(f,\alpha) = \rho g F(f,\alpha) \qquad (2.15)$$

The radiation stress Sxy is conserved up to the breaker line, is independent of the location, and it contains all the angle information. To calculate the phase speed at breaking, it is assumed that the waves at breaking are in shallow water so that it is given by

$$C_b = \sqrt{g h_b} \qquad (2.16)$$

where C is non-dispersive (i.e. independent of frequency)

To calculate the breaker depth (h_b) in equation 2.16, it was first necessary to calculate the breaking wave height. It is assumed the breaking wave height can be approximated by the calculated wave height in 4 meter depth

$$Hrms_b \simeq Hrms_{4m}$$

(2.17)

Calculation of wave heights at 4 meter contour is achieved by computing the total variance (energy) from the directional spectrum.

$$\int\int E_{4m}(f, \alpha) df\, d\alpha = \sigma_{4m}^2$$

(2.18)

(applicable strictly only for narrow band system) where $F_{4m}(f, \alpha)$ in 4 meter is given by equation 2.9. For narrow band waves (Longuet-Higgins, 1980).

$$Hrms_b = \sqrt{8}\,\sigma_{4m} \simeq Hrms_b$$

(2.19)

Since wave heights in the inner surf zone are strongly depth dependent, the envelope of the breaking wave heights is described by (Thornton and Guza, 1982) as

$$Hrms_b = 0.44\, h_b$$

(2.20)

and the breaking depth is calculated as;

$$h_b = \frac{Hrms_{4m}}{0.44} = \frac{\sqrt{8}\,\sigma_{4m}}{0.44} = 6.4\,\sigma_{4m}$$

from which the phase speed at breaking is calculated

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In calculating the longshore energy flux from equation 2.14, a transfer function is specified that contains all the wave transformation information from deep water to the 4 meter contour and does not vary from day to day.

$$H^2(F) = \rho g K_r^2(\alpha, F) K_s^2(F) \cos\alpha_s(F) \sin\alpha_s(F) \frac{C_{g_s}(F)}{C_s(F)} \quad (2.22)$$

Therefore

$$P_{l_b}(\alpha_s, F) = \underbrace{H^2(\alpha_o \alpha_s, F)}_{\text{fixed}} \quad \underbrace{F(\alpha_o, F) C_b(F)}_{\text{varies daily}} \quad (2.23)$$

The longshore energy flux was calculated every six hours and summed to give yearly values for a period of 18 years (1964-81). The results are shown in table 9 The values, given in newtons per year, were then converted to (ft-lb/sec/linear ft of beach). Finally, the net longshore sediment rate was calculated by applying equation 2.12 and the results are shown in Table 10.
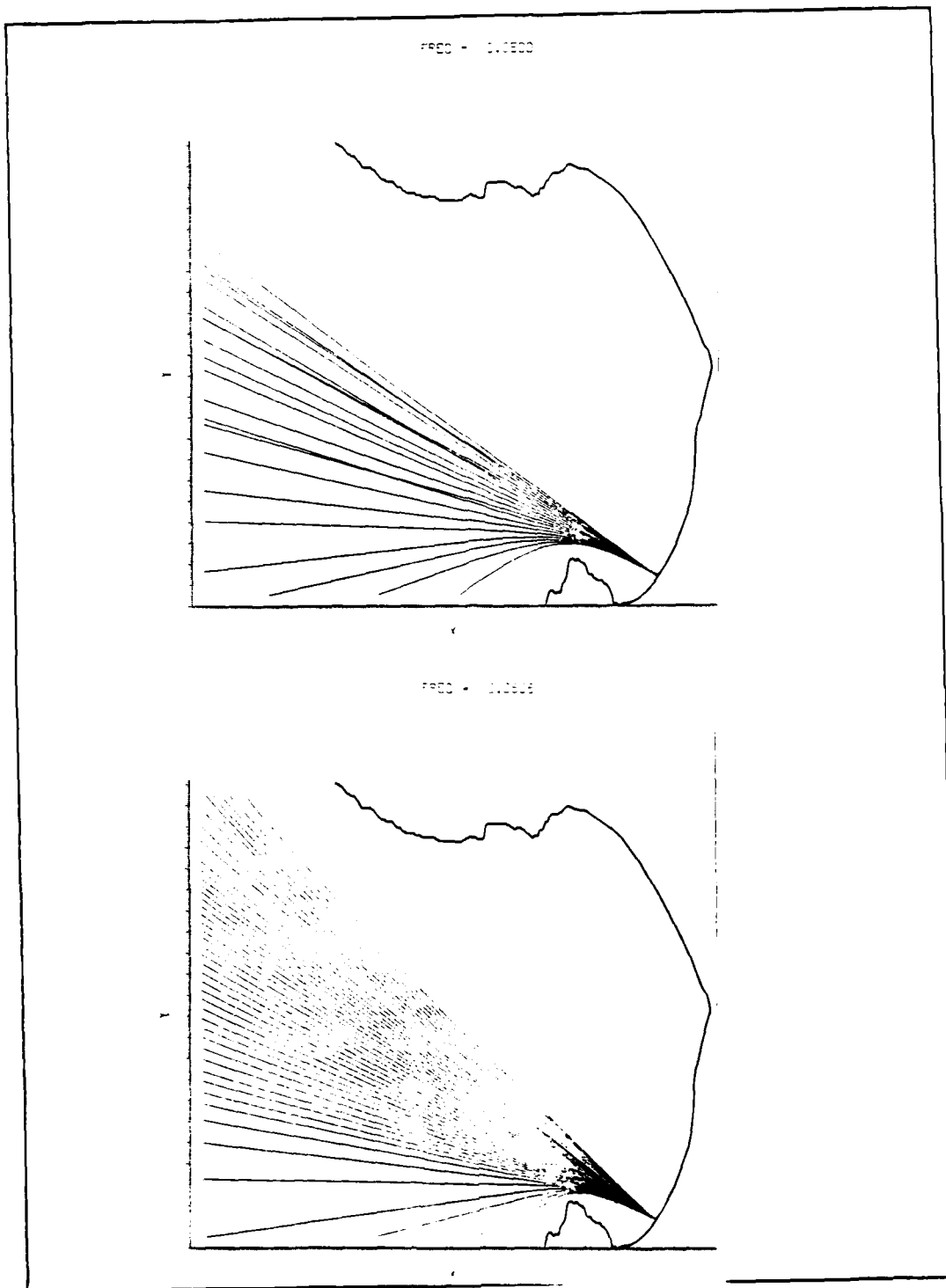
Figure 2.5   Wave Refraction Diagrams For Station 2.

FREQ - 0.0500

FREQ - 0.1333
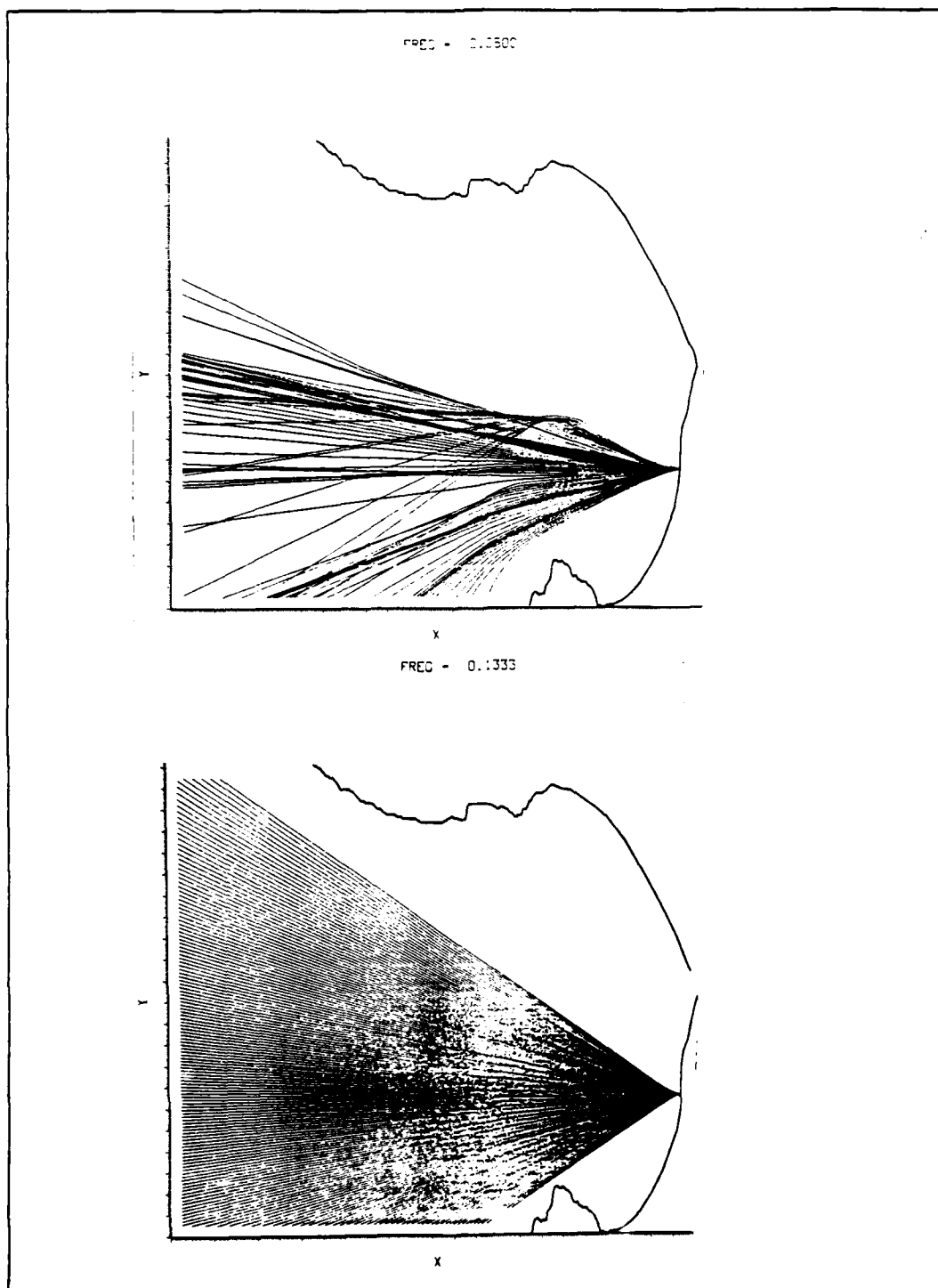
Figure 2.6   Wave Refraction Diagrams For Station 6.

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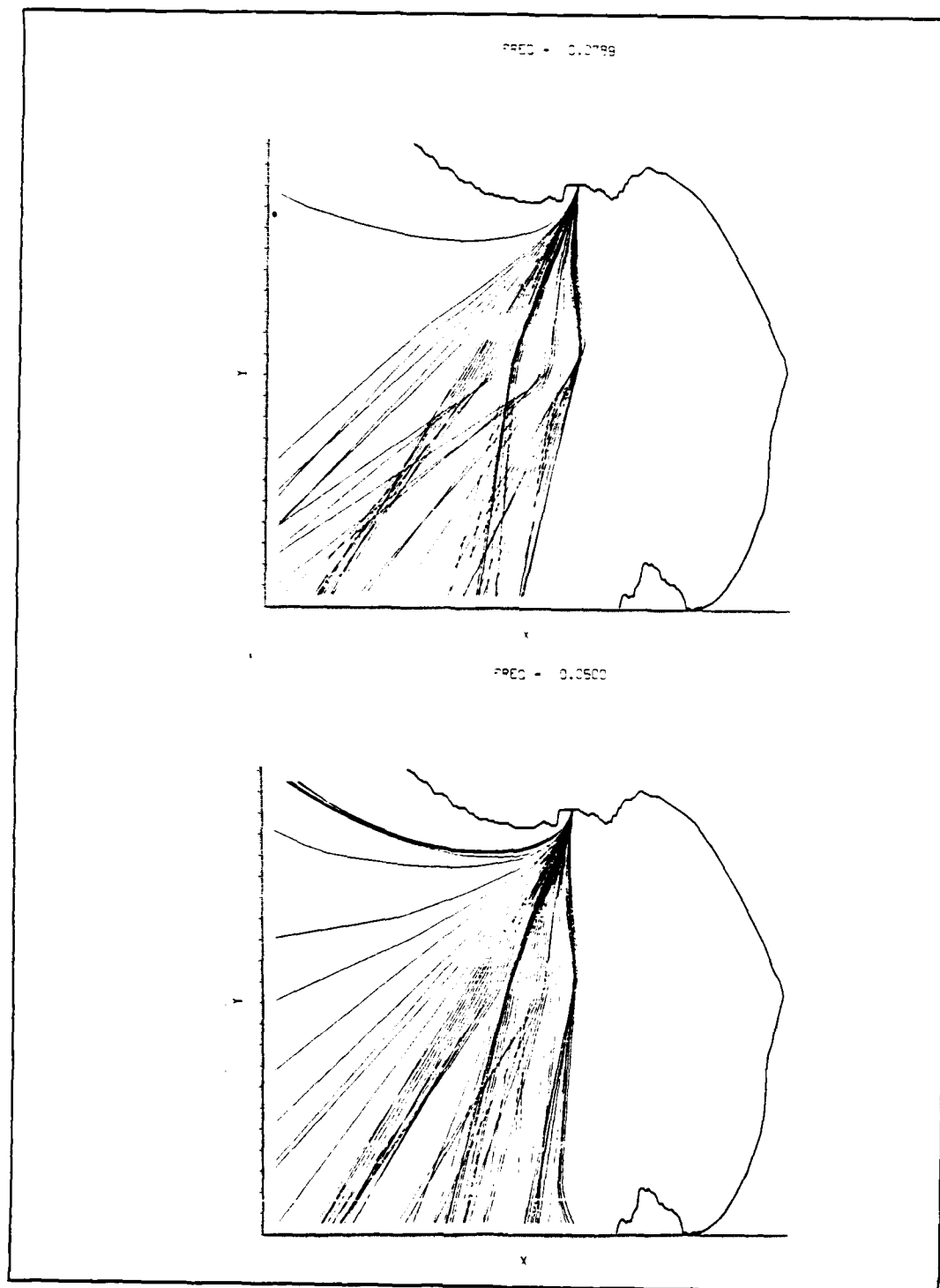
Figure 2.7   Wave Refraction Diagrams For Station 15.
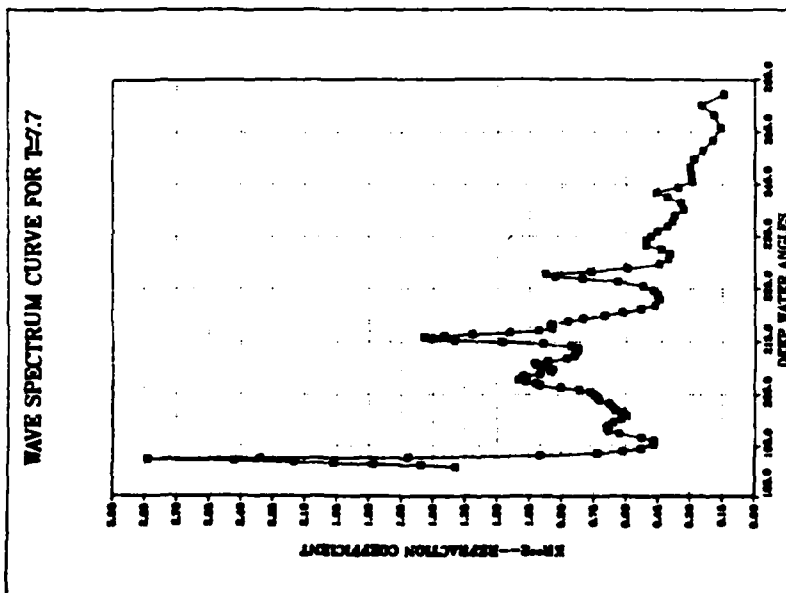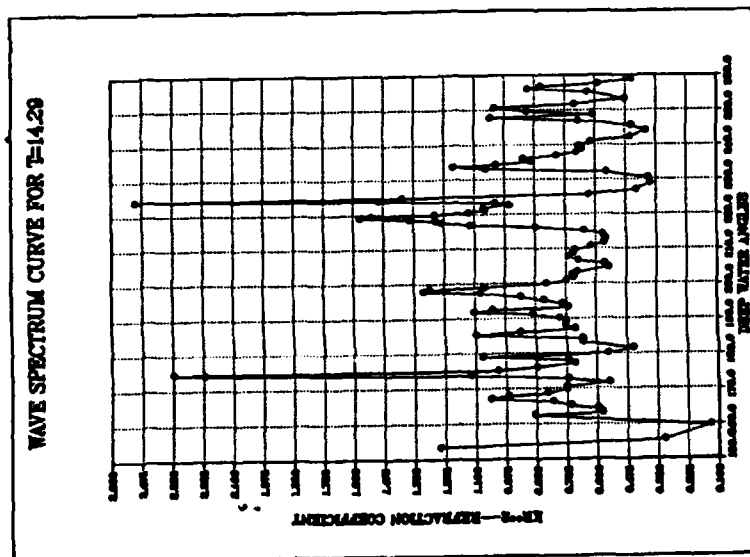
Figure 2.8   Refraction Coefficients As
A Function Of Nearshore Angles.STATION 15

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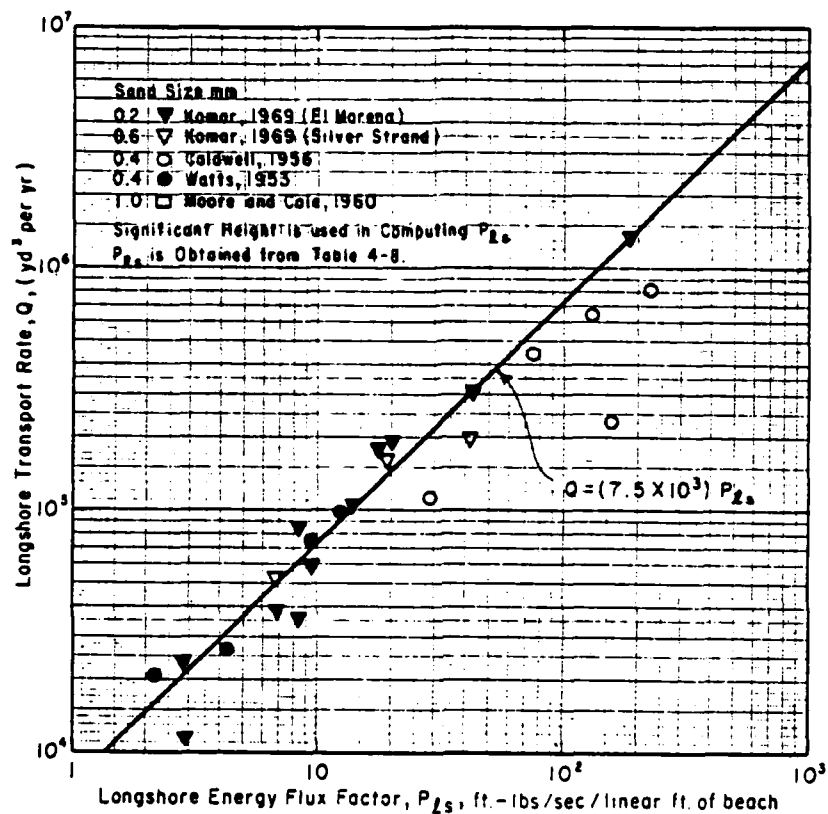
Figure 2.9 Longshore Curve For Determining K.
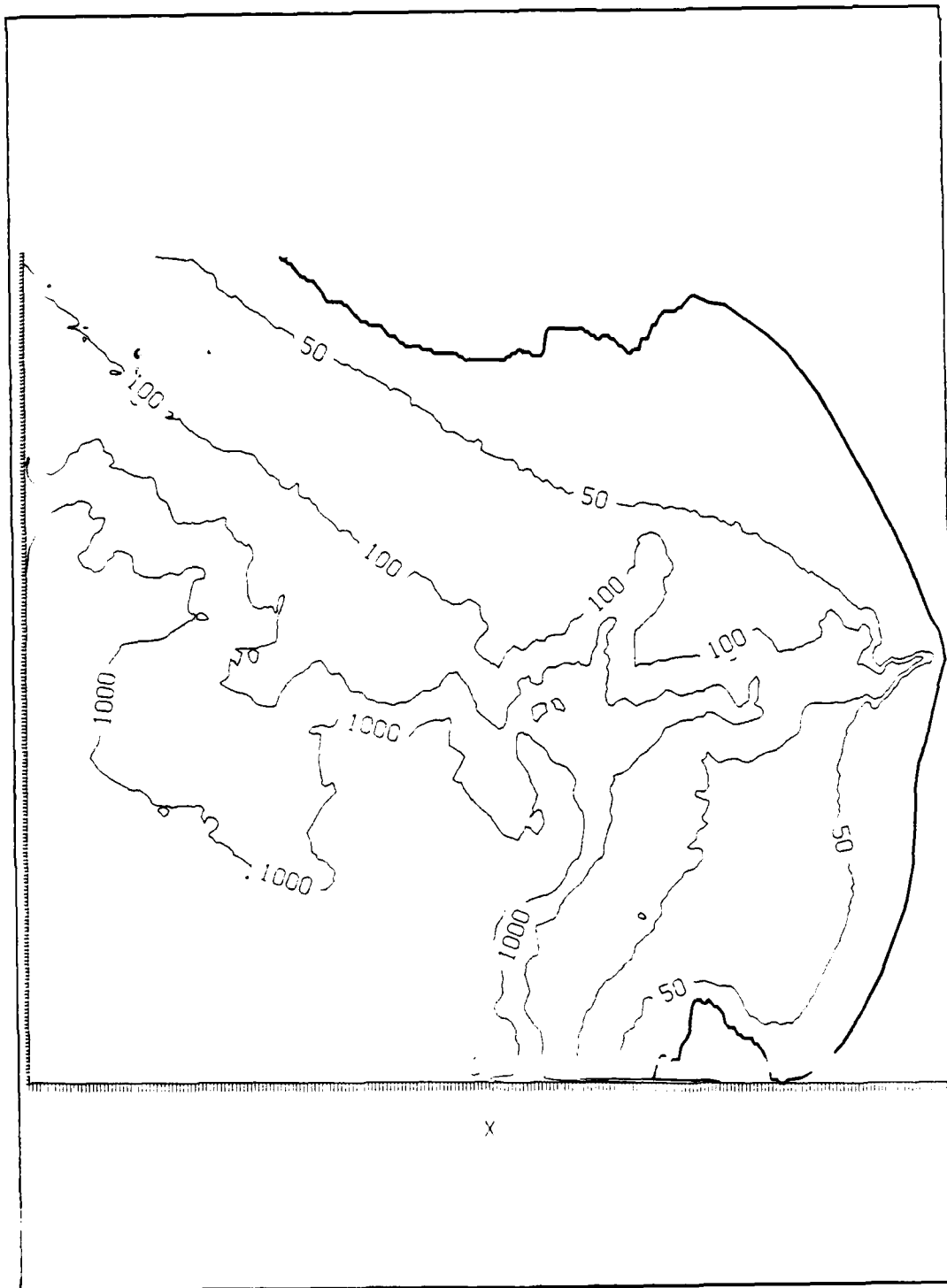
Figure 2.10   Bathymetry Of The Study Area.

6. Results

Based on energy flux approach (Table 10), the study shows both upcoast and downcoast trend of longshore transport in Monterey Bay, with the downcoast drift dominating. In the northern bay, the maximum downcoast drift occur around Santa-Cruz Harbor, with upcoast flow from Sea-cliff beach, increasing to La Selva Beach. South of the Pajaro River, the transport flow is downcoast towards Moss Landing.

In the southern bay, the maximum downcoast flow occurs at Marina, and continues down to Monterey Harbor. However there is a maximum upcoast drift at the mouth of the Salinas River indicating the insignificant contribution of the Salinas River to the southern beaches as was stated by Porter. et. al (1979). Hence large amount of erosion occur south of the Salinas River. Because of these upcoast and downcoast drifts, a net longshore drift was found and an average longshore transport rate at each location was calculated as 4.1×10^5 cubic yards per year.

7. Sensitivity Study

A sensitivity study was made to assess the possible errors associated with specifying nearshore angles in the littoral transport calculation. Taking station 6 (see figure 2.11) as an example, the shoreline was varied by ±1 and ±2 degrees, and the littoral transport calculated. The results (see the table below) show almost a linear change in the littoral transport with change in angle. For small angles, angle information in the longshore power formula (equation 2.14) can be approximated as

$$\sin(\alpha) \cos(\alpha) \simeq \alpha$$

Thus, errors in shoreline inclination will give linear change in the littoral transport calculation.
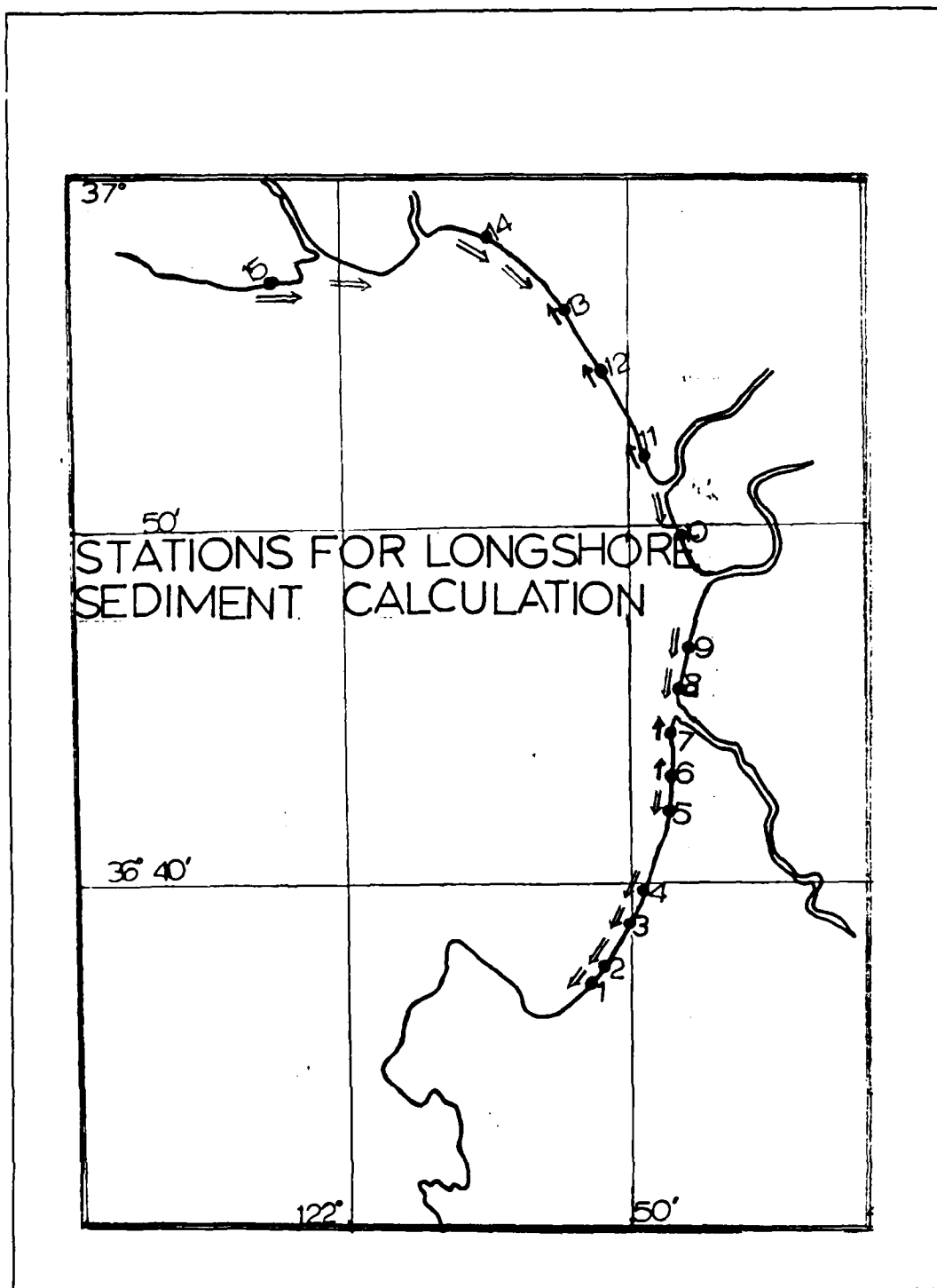
Figure 2.11   Stations For Longshore Sediment Calculation.

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TABLE 9

LONGSHORE COMPONENT OF WAVE ENERGY FLUX–IN NEWTON PER YEAR

YR / sn	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
1	41.4	35.3	28.3	36.7	44.3	43.8	60.4	67.5	91.3	79.4	86.0	44.7	84.5	63.2	66.5	97.9	114.1	102
2	41.3	37.6	30.2	36.6	44.2	43.1	63	70.5	86.9	75.1	92.9	153	89.7	63.2	74.9	100	121	106
3	10.1	25.3	20.9	9.6	19.9	-3.9	47.9	51.1	2.9	-23	79	129	-104	-54	42.6	-50	210.7	-17.7
4	59.1	53.3	48.4	47.2	66.6	37.5	123.2	128.3	87.1	59	172	297	22.2	252	129	555	147	836
5	26.5	190	156.2	225.0	249	280	342	379	556	518	479	779	843	556	455	772	835	747
6	-61.8	-36	-65	-55.7	-138	255	150	-195	-296	312	143	-187	-3·35	-369	-492	-305	-36	-401
7	398	-244	-21.7	-383	-352	-118.1	77.7	682	-176	-283	102	287	-219	-292	34.8	-46	206	359
8	169	108	74.4	143	143	167	267	302	365	304	363	701	618	275	29.5	399	518	402
9	10.6	-5.9	-7.5	28.5	20.3	9.6	111	128	-27	-55	160	371	426	-63	70.5	189	-10.6	-71.1
10	62.4	-9.3	-3.7	-6.6	21.6	82.4	102	103	153	151.1	139	242	479	167	115.7	218	200	198
11	-89	-132	-96	-75	-133	-126	-14	-49	-227	-253	-66	31.6	119	-209	-43	-311.9	-223	-28
12	62	-214	45.3	116	-224	-116	-137	-108	-395	-428	-65	4.5	48	-311	-63	-439	-355	401
13	-113	-173	-115	-74	-165	-144	-12	-49	-270	-289	-27	91.6	189	-200	-13.2	-247	-17.8	-220
14	14.8	-19.4	-6.3	7.5	-17	11.9	9.2	0.44	23	377.1	151	199	406	444	17.3	906	62.7	67.6
15	433	556	332	389	586	773	183	377	1296	1304	370	339	525	1202	352	1516	1285	1414

TABLE 10
LONGSHORE SEDIMENT TRANSPORT RATE

$$Qs = (7.5 \times 10^3 P) \text{ CUBIC YARDS PER YEAR}$$

STATIONS	LONGSHORE ENERGY FLUX (NEWTON PER YEAR)	LONGSHORE SEDIMENT TRANSPORT RATE (CU.YDS/YEAR)$\times 10^5$
1	71,534	3.3
2	73,920	3.4
3	10,794	0.5
4	91,084	4.2
5	479,361	22.0
6	-134,934	-6.2
7	-83,699	-3.8
8	313,218	14.4
9	51,777	2.3
10	138,408	6.4
11	-121,333	-5.6
12	-201,938	-9.2
13	-111,643	-5.1
14	22,603	1.0
15	735,587	33.8

UPCOAST DRIFT   = -29.9×10^5

DOWNCOAST DRIFT = 91.3×10^5

NET LONGSHORE DRIFT = 61.4×10^5

AVERAGE LONGSHORE TRANSPORT RATE= 4.09×10^5

AT EACH LOCATION.

TABLE   10A

LONGSHORE POWER AS A FUNCTION OF

VARIABLE SHORELINE ORIENTATION

ANGLE VARIATIONS	LITTORAL TRANSPORT
	(cubic. yards/year)$\times 10^5$
-2	+2.0
-1	-2.1
0	-6.2
+1	-10.4
+2	-14.3.

The sensitivity results emphasize the need for specifying angles carefully, and also shows why the computed mean sediment transport appear noisy (variable) along the shore.

8. Discussion

An objective of this work is to develop a sediment transport model based on spectral wave approach. Improvements over previous works include using a wave spectrum, a numerical refraction program running a large number of rays that could be averaged, and an application of an eighteen year wave climatology. Over all the model produces transport in the same order of magnitude as the earlier estimates.

The transport relationship (Qs=KP) is an approximation . Moreover, the littoral drift considered in the study is not the actual drift, but the potential drift. Potential littoral drift is the maximum drift that can be

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supported by the existing wave conditions. It represents the drift that would be expected to occur under the influence of waves if an unlimited supply of sand is available. The actual drift would not exceed the potential drift.

The linear refraction ignores wave diffraction. If wave crests are not uniform along a wave front, wave energy will be laterally diffused. In this work we delete refraction coefficients exceeding 3, and average over directional band intervals.

Another assumption made was that the directional wave distribution is uniform when applied to the spectral model input. In reality, the directional wave distribution is non-uniform. The uniform directional distribution was chosen as a way to smooth the refractive effects partially accounting for diffraction.

Presumably the choice of K value affects the validity of the computed results. No differentiation between the bed load and the suspended load transport is made. Moreover, the formulation does not account for the sediment grain size or the beach slope, both of which may influence transport rate. Uncertainty in the value of K introduces uncertainty in the power equation. Specification of K need to be improved. Bailard (1984) finds K as a function of the incident breaker angle and the ratio of orbital velocity at the breaker point divided by the sediment fall velocity. Field observations also suggest a trend of decreasing K with increasing sediment diameter (Dean, 1985). Choice of K as a constant is applicable only for certain range of values for grain size and range of wave height.

III. SEDIMENT LOSSES IN MONTEREY BAY

Sediment losses from the beach areas in Monterey Bay are due to offshore deposition, wind deflation, deposition into the submarine canyon and coastal sand mining. The presence of extensive sand dunes along the central and southern portion of the bay indicate that wind loss is considerable. A history of sudden deepenings at the head of Monterey Submarine Canyon indicates that considerable material may be lost to the offshore areas by slumping into the canyon.

A. SUBMARINE CANYON

The predominant offshore feature within the bay is the Monterey Submarine Canyon, which cuts across the shelf in the center of the bay. Submarine canyons provide a conduit for sand to move from shallow to deep water and a canyon that heads close to the shore will funnel sand out of the littoral zone. The Monterey Submarine Canyon is the principal sink for sand from the Salinas River (Dingler. et al, 1985). Although there have been a number of papers dealing with the Monterey Submarine Canyon; such as Wilde (1965), Martin and Emery (1967), and Starke and Howard (1968). It has not been possible to volumetrically estimate losses of sediment to the canyon simply because very few direct and indirect measurement have been made. To that effect, much reliance has to be placed on the literature to make an approximate estimate of sediment loss.

Wilde (1965) estimated that 13×10^5 cubic yards of beach sand per year moved through Monterey Canyon and reached its fan; half of this sand came from north of the canyon and the other half from the Salinas River. His estimate was based on repeated surveys of the head of the canyon at regular intervals to determine sand accumulation and removal.

Welday (1972) working on the southern cell and utilizing Wilde's method and estimate concluded that about $6.5x10^5$ cubic yards of sand are deposited annually into the canyon. Arnal.et al.(1973) estimated that the deposit into the canyon was about $4x10^4$ cubic yards per year. Their estimate was based on soundings, dredging and visual observation of the bottom topography conducted by divers in August 1967 at the end of the pier at Moss Landing Harbor, and on the results of Moss Landing dredge spoil project of 1971-73. Dingler (1985), after reviewing the works of Wilde, Welday and Arnal.et. al, estimated that at least $3.0x10^5$ cubic yards of sand are deposited annually into the canyon from the Southern cell. Approximately $9.5x10^5$ cubic yards of sand are derived annually from the Salinas River(see table 6) and since the canyon is the main sink for the river's sediment, a significant amount of the sand is lost to the to the canyon.

In the Santa Cruz cell, Dingler.et al (1985) established that due to lack of other major sinks, essentially all of the $6.5x10^5$ cubic yards of sand per year, moving along the shore either move into the Southern Monterey bay cell or enter the submarine canyon on reaching the southern end of the cell. Yancey (1968) and Wong(1970) concluded that no sand by passes the canyon head. Due to the variability in the longshore current at some periods of year, and the existence of rip current around the head of the canyon, appreciable quantity of sand normally bypass the canyon (Dingler.et.al, 1985) From all these data, it is envisaged that at least $9.0x10^5$ cubic yards of sand are deposited into the canyon, with about $4.0x10^5$ cubic yards from Santa Cruz cell, and about $5.0x10^5$ from southern cell. This estimate was arrived at by judiciously reviewing previous works and historical data on Monterey Submarine Canyon.

B. OFFSHORE LOSSES

A significant amount of sediment in the littoral cell is deposited offshore mainly by rip currents which act extensively along the shore. The formation of these currents and their effects have been mentioned earlier. Invariably, all researchers agreed that large amount of sediment are being deposited offshore as indicated by changes in bathymetric contour of successive survey.

Arnal. et. al (1973) postulated that the quantity of sand moved towards and away from the shoreline may be estimated precisely by determining changes in level over a number of years. This was obtained by measuring the changes in area within bathymetric contours and shoreline, and multiplying by half the contour interval. Using the (1911) and (1956) editions of the coast and Geodetic Survey charts (5403) they calculated that about 7×10^5 cubic yards of sands per year are lost due to shelf deposition. Considering that the impact and effects of the rip currents were not fully taken into account, the above value is underestimated. Hence an estimate of 8.5×10^5 cu. yds is recommended.

C. LOSSES BY DEFLATION

Where there is a large supply of sand from longshore transport, the existence of wide sandy beaches, a predominant strong onshore wind and low coastal topography, wind transported sand can develop a major dune system landward; hence, the eolian component of the total sediment budget may be substantial. The extensive dune field in Monterey Bay extending from Sunset Beach to the southerly end of the bay near the City of Monterey, and the continuing occurrence of dune encroachment as seen from both aerial photographs and field observation strongly indicate the effect of eolian sediment transport.

Sand that is blown landward accumulate in dunes, act as short-term or long-term sediment sinks because it is

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effectively removed from the influence of average nearshore hydrodynamic processes. Secondly the coastal dune field is a reservoir of beach sand that can supply sand when the beach is eroded. Thus, during local storm conditions, with elevated water level and increased run up, these dunes may be mined and the stored sediment returned to the beach system. Finally, a well developed foredune system acts as a sea-wall to prevent wave and flood damage landward of duneline during period of high water level caused by storms. For these reasons, it is important to estimate the rates of movement of sand from the beach landward into the dune areas so that measures of net accumulation (either as storage or sink) can be obtained.

Field and laboratory studies Bagnold (1941) and Chepil (1945) indicate that three mechanisms are responsible for the transport of sediment by winds, namely: SALTATION, SURFACE CREEP, and SUSPENSION.

Saltation is the predominant mode of sand transport by wind and often account for up to 80% of the total transport load. Sand particles acted by hydrodynamic lift, rise from the surface at a nearly vertical angle, travel forward in an arc, and land. Upon landing they may jump or saltate again or they may dislodge other particles that saltate.

About 15% of total wind transport is transported by sliding or rolling of particles in continuous contact with the bed. This is referred to as creep, and it involves the larger sand grains. The driving forces are wind stress and the impact of saltating grain. Owing to the low density of air, a negligible volume of sand particle having diameter larger than 0.1mm is carried by turbulent suspension. Suspension mechanism contributes less to the system.

D. FIELD MEASUREMENT OF EOLIAN TRANSPORT RATES

There are two primary methods of predicting eolian sediment transport rates. The first involves measurement of

volumetric changes in dune systems as indicators of net accumulation. This method was used by Arnal.et.al,(1973). The method can be accomplished through either repetitive, detailed field mapping of the dune system or through repetitive analysis of high resolution topographic map series based on aerial photography.

There are three major problems one encounters using this approach. Firstly, either field mapping or topographic map analysis requires a large amount of detailed informations and tedious methodologies. Secondly, for many locations, contour interval of less than (50 cm) are probably desirable in order to accurately approximate annual change over a large area. The required information invariably does not exist for many areas of concern and its acquisition may be very expensive. Finally, where new data sets are being obtained, many years of acquisition will be needed before substantive results can be obtained. For these reasons, it is desirable to use the semi-empirical predictor equation. This method involves the use of physically based models to predict rate of sand movement. These models usually require information on local wind velocities and sediment sizes. Several authors, example; Orien and Rundlaub (1936), Bagnold (1941), Kawamura (1951) and Zingg (1953) developed semi-empirical predictor equations for wind transport rate. Of these equations, Bagnold's equation is most commonly used. He employed a momentum analysis to evaluate saltation load and added 25% for creep. His equation for dry sand is:

$$Q = C(d/0.25)^{1/2} \, \rho_a \, U^3 \qquad (3.1)$$

Q = rate of sand transport per unit width
C = local wind speed
d = median grain diameter in (mm)
U = shear velocity
ρ_a = air density

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Owing to time constraint, it was not possible to acquire the necessary data for a predictor model. To that effect, the application of this formula requires a long term data. Hence, it became necessary to rely again on literature as a basis for estimation. Arnal.et al,(1973) made planimetric measurements of the volume of sand dunes along the bay. Eight areas were chosen,and volume of successive 'slices' of dunes were calculated. Summing up the volumes as shown in Figure 3.1 for the eight areas, they estimated that the volume of sand loss by deflation was between 32,000 to 53,000 cubic yards annually, of which about 3% occured north of Monterey Canyon. Dingler.et al 1985, using Arnal.et.al's calculation, estimated at least 39,000 cubic yards of sand is lost annually by deflation. From these estimates, a total of 50,000 cubic yards may be a reasonable rounded figure for annual loss by deflation. One element of the State of California Monterey Bay Erosion Study is to measure eolian transport in the field to improve present estimates. Eolian transport is not a major source or sink, but the preservation of sand dune may depend on a better understanding of the processes involved.

E. LOSSES BY SAND MINING

Erosion of the Southern Monterey Bay coastline is a major concern to the local sand industries as well as environmental and regulatory agencies. Sand for commercial use has been dredged for the last 70 years (Osborne, 1978). Removal of sand by mining companies from the surf zone, beaches and dune areas, constitutes a major loss of sedimentation to the Bay, and hence can be considered a significant factor in the sand budget.

The simplest method to obtain a numerical value of the volume of sand extracted by mining operation would be to go to each mining company and obtain the data. This method
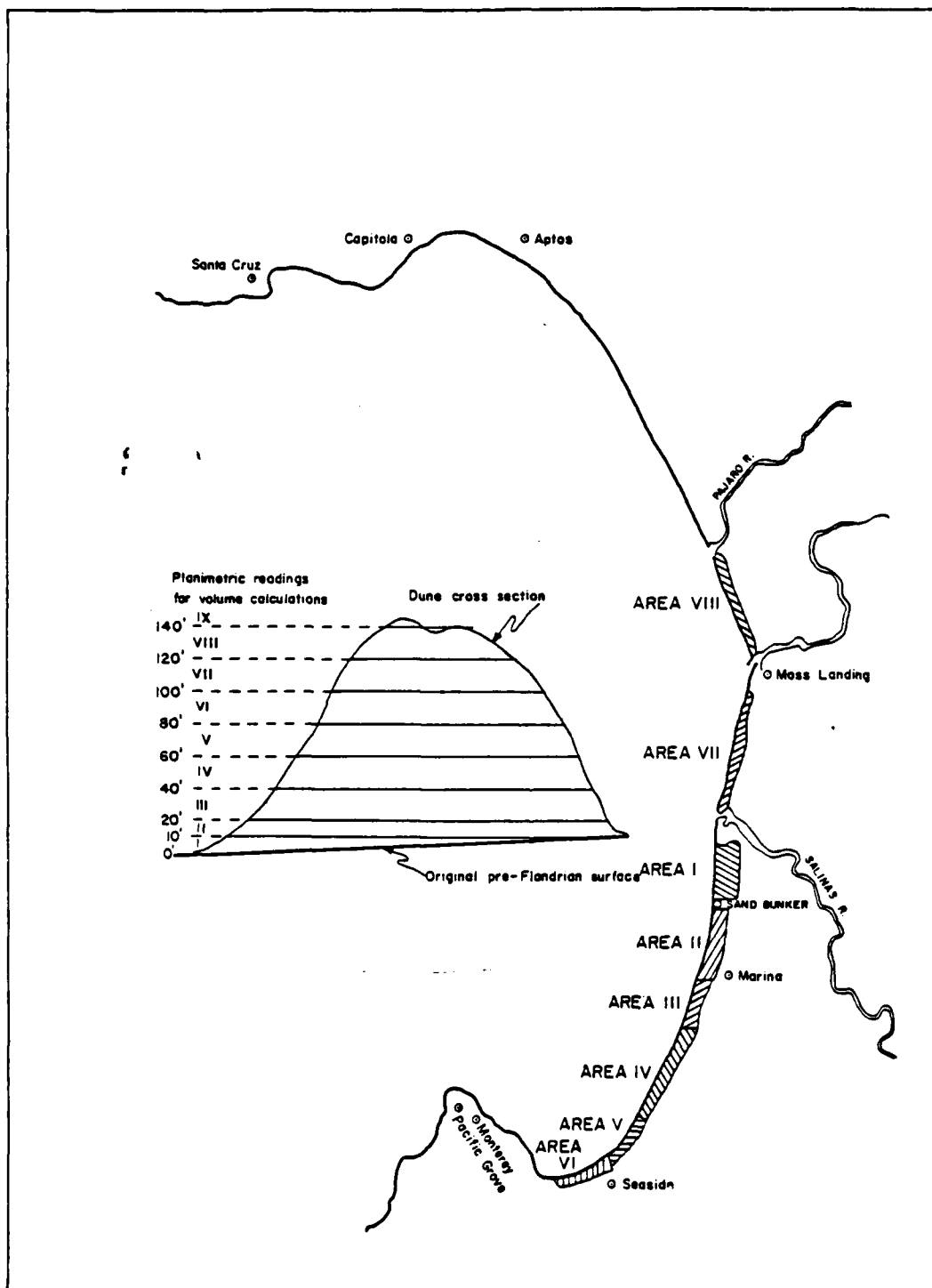
Figure 3.1   Planimetric Measurements Of Volume Of Sand Dunes.

failed owing to the fact that the companies are very secretive about their operations, and have even instructed their workers not to divulge any information about their activities. This attitude has become even stricter in recent years as the pointed questions raised by aggressive conservationists regarding coastline recession due to mining make them more conscious of the long term effect of their operations (Arnal, 1973). Hence, when calculating sand budgets, one could only estimate the loss due to mining operation because the sand mining companies will not release their figures. These budget estimates were therefore subject to errors.

Sand and gravel deposits through out Monterey County and their commercial exploitation, have been documented by Goldman (1964), and Hart (1966). The U.S. Army Corps of Engineers (1959) estimated that the average rate of sand removal by mining operation is around 75,000 cubic yards per year. The accuracy of the estimates gathered from these references is questionable since figures on annual production were not obtained from the individual companies.

The average amount of sand extracted by miners from the littoral cell was approximated at 330,000 cubic yards per year by Allayaud (1978). This amount is based on all available estimates and figures, including numbers submitted to the staff of the Regional Coastal Commission by Monterey Sand Company at the time. This figure is comparable to the estimates by Dorman (100,000 cubic yards) Arnal. et. al (250,000 cubic yards), and Welday (250,000 cubic yards), as seen from Table 1. Owing to greater building, and increased demand for special industrial sands for sand blasting, surface finishes, filtration and foundry casting, these amounts are likely to increase. Monterey Sand Company reported in 1978 that they have increased extraction by 20%, (see Allayaud, 1978). With expected increase in demand for

the by-products, the extraction rate would be increased accordingly. Assuming that the other companies increase production owing to the economic desirability of these sands, it is estimated that an increase of about 60 percent can be envisaged. Working on this assumption, the average volume of sand loss by mining operation is estimated to be around 5.0×10^5 cubic yards per year. This figure, like other previous figures is purely an estimate and should be used with caution. They all seem to indicate that sand mining contributes significantly to coastal erosion.

Arnal(1973) emphasised that coastal erosion would undoubtedly take place even if sand mining operations are terminated. However, mining operations in areas where erosion occurs do make the process worse in its effect. He therefore recommended finding alternate sources of sand supply for the companies. Even though they are not solely responsible for coastal erosion, their activities make a bad situation worse.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY OF FINDINGS

A budget deficit computed to be (2.5×10^5) cubic yards per year, suggests that erosion is continuously occurring along the Monterey bay. The results shown in Figure 11, portray that sand mining activity is a significant factor in erosion processes, contributing to about 24% of the total losses. If sand mining operation are completely eliminated, the sediment losses would be around (18.0×10^5) cubic yards annually, while the gains remain around (21.1×10^5) cubic yards, indicating a budget surplus of (3.1×10^5) cubic yards per year (accretion). The results show more sedimentary activities in the southern littoral cell than in the northern littoral cell. Of the total losses in the entire Monterey Bay, 72% came from the southern cell, indicating that coastal erosion is more persistent in the southern cell than in the northern cell. The deposition from the Salinas River appears to be the largest source of sediment, but most of the sand delivered by the river are either lost to the Monterey Submarine Canyon, or are deposited in the Salinas River Delta, or are even transported north of the Canyon. The littoral transport analysis (Figure 2.11) suggests a null point between stations (5) and (6) which indicates that the area is the northern boundary of the southern cell. If this is true, then the area between the Salinas River and the Monterey Submarine Canyon should be treated as a separate littoral cell. This finding is of particular interest for further analysis.

B. CONCLUSION

Quantitative and detailed conclusions are presented at the end of each section based primarily on information and

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                         TABLE 11
          SEDIMENT BUDGET RESULTS FOR MONTEREY BAY


                     (CU.YDS./YEAR)x10⁵
   A.                      NORTHERN LITTORAL CELL

        CREDITS                        DEBITS

   CLIFF EROSION   = 1.3      SUBMARINE CANYON = 4.0
   RIVER DISCHARGE = 1.47     OFFSHORE DEPOSIT = 2.5
   LONGSHORE DRIFT = 3.5      WIND DEFLATION   = 0.1
                              SAND MINING      = nill

   B.                      SOUTHERN LITTORAL CELL

   CLIFF EROSION   = 4.3      SUBMARINE CANYON = 5.5
   RIVER DISCHARGE = 9.7      OFFSHORE DEPOSIT = 6.0
   LONGSHORE DRIFT = 4.1      WIND DEFLATION   = 0.4
                              SAND MINING      = 5.4


   TOTAL SEDIMENT GAINS  = 20.9
   TOTAL SEDIMENT LOSSES = 23.4
   BALANCE               = -2.5, which implies erosion
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results described in that section.   The reliability of the
data and the mathematical models which form the basis of the
computational results were analyzed.   The premises of these
conclusions were discussed and their merits and demerits
analyzed.   Moreover, the sources of the data and the
relevant historical informations were made available so that
a reader may make his own independent appraisal of the
validity of each section and the authenticity of each
conclusion.   Each of these conclusions is principally the
subjective view of the author.

The sand budget is a useful approach in analyzing the coastal erosion problem. Although it cannot obtain a quantitative estimates of the rate of erosion of the coastline, nor the effects of major sinks on the erosion rate, budget calculation may be useful to show a trend. Once an erosion trend is evident from the deficit nature of the budget, a correlation may be established between the deficit and the rate of erosion. Furthermore, it allows a rough estimate to be made of what percentage that is attributable to each of the major sinks.

There were a number of limitations encountered in this study. The lack of more certain values for the budget components is primarily due to the incomplete nature of the input data needed for the computations. To that effect, much dependence was made on works of previous authors in arriving at subjective evaluations.

C. RECOMMENDATIONS

It can be seen that the volumetric contributions of all the major sinks in this study were gross estimates based on previous studies. The accuracy of these figures may either have been overestimated or underestimated, hence they are surely in error. These errors are due to the fact that there are no longterm observations backed by experiments on these sinks. In the case of sediment sources, owing to the availability of data, mathematical models were developed leading to fairly reliable computations. The reader can see that there is disparity on the validity of the results. Whereas sediment sources are backed by mathematical hypotheses, the sinks are coarse estimates. Hence in future studies of this nature, the following recommendations are suggested in order to modify and refine the present work.

A review of the literatures shows no site specific studies have been done to estimate the rates of sand movement into the canyon and offshore deposition due to rip

current.   These   two phenomena form   the major   sink.   The
effects   of   the   down canyon   turbidity   currents   and   rip
currents   should   be   investigated.   A   combination   of
bathymetric survey and experiments as done by Moss Landing
Dredge   Spoil Project   1971 could   be expanded   on a   larger
scale to determine changes in bottom elevation.   For eolian
transport predominant in   the southern cell,   a predictor
model could   be designed to   correlate the   eolian transport
rate and local wind velocities.

The episodic nature of sediment input due primarily to
wave   action on   cliffs   and   excessive runoff   by   flooding
create   great   variability   in the   sediments   supply   rate.
Appropriate   study   should   be conducted   to   estimate   this
variability in   supply rate which often   occurs infrequently
when   high tides   coincide   with   stormy weathers   and   also
during severe winter rain fall.   Efforts should be made to
establish a relationship between   intense storm,   runoff and
cliff recession rate.   A part of the Monterey Bay Erosion
Study is to   measure cliff recession from   historical aerial
photographs.   Efforts should be made to transform equation
2.4 into   an   empirical   model   for   predicting   the   cliff
recession rate.

Sediment   discharge   data   have been   acquired   for   the
various rivers over a long period of time.   In most cases
only river flow discharges are available,   and not suspended
nor   bed   load   discharges.   To   determine   accurately   the
sedimentary contributions of these rivers, gaging stations
should be   set up   at the   mouths and   other parts   of these
rivers and   maintained for   several years   so as   to collect
longer period   sediment data.   The daily   discharge records
could be used   to extrapolate the sediment discharge over a
longer period of time.

The   wave   spectral   model used   in   longshore   sediment
transport   ignored   the   effect of   wave diffraction.   Wave

diffractive effects tend to smooth the energy, thereby affecting the validity of our results. Although corrective actions were taken to offset the effects of diffraction. It is suggested that the wave spectral model be refined to include diffraction.

D. HUMAN IMPACT AND EROSION PROBLEM

Sand mining activities can be viewed as one of the human impacts on the Monterey bay which inevitably diminishes the volume of sand deposited in the littoral cell and significantly account for erosion. The sand mined from the Southern Monterey Bay have unique characteristics-silica content, hardness, roundness and a spectrum of sizes. Contrary views have been expressed on the origin of the mined sands. It is now imperative that further research be done to determine the ultimate sources of the beach sand, and a complete evaluation of the quantity and characteristics of mined sand should be performed to assess the impact of sand mining on coastal erosion. Although it is evident that without sand mining, longshore sediment transport will still occur and certain amounts of sediment will still be permanently lost offshore. However, sand mining mining is worsening an already bad situation (the natural processes of shoreline retreat) and there is a dire need to reduce erosion damages.

Two basic approaches are advanced in combating erosion menaces. The structural method which slows down erosion processes by constructing protective devices such as rip-raps revetments, bulkheads, sea-walls, groins or nearshore break-waters to protect against wave attacks or to stabilize the bluffs. Protective measures have been used around Fort Ord and other severe erosion areas. They are exorbitantly costly and short period results are achieved. The second method is the land use control method which primarily is adjusting land use to the erosion hazard by

setting structures back a safe distance and controlling runoff. Establishing a safe setback involves determining shore recession rate, identifying areas subject to erosion and selecting length of time during which regulated uses are to be protected from recession. The recession rate setback distance is evaluated by multiplying the average annual shore recession rate by the assigned desired life of the structure to protected. Once this setback rate is established, the erosion hazards faced by property owners and estate developers can be controlled.

APPENDIX A
STREAM GRADIENTS FOR SALINAS, PAJARO AND SAN-LORENZO RIVERS
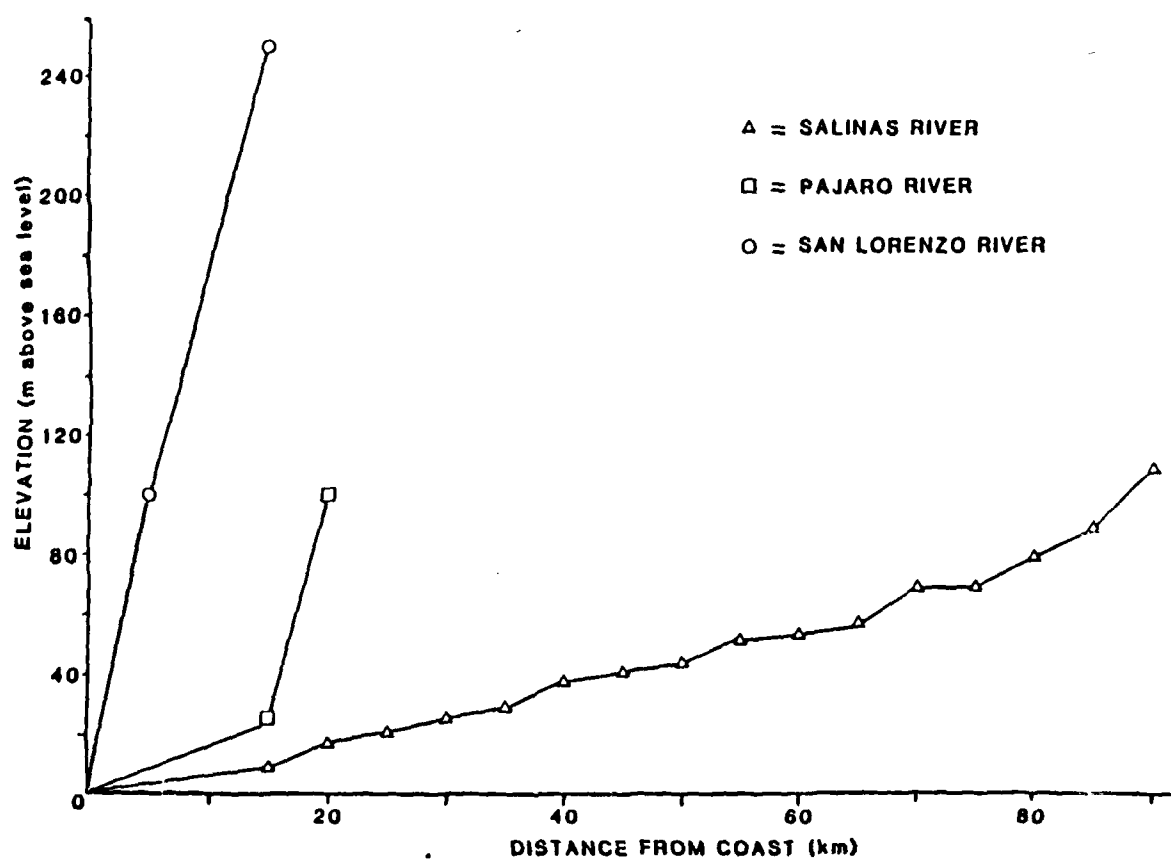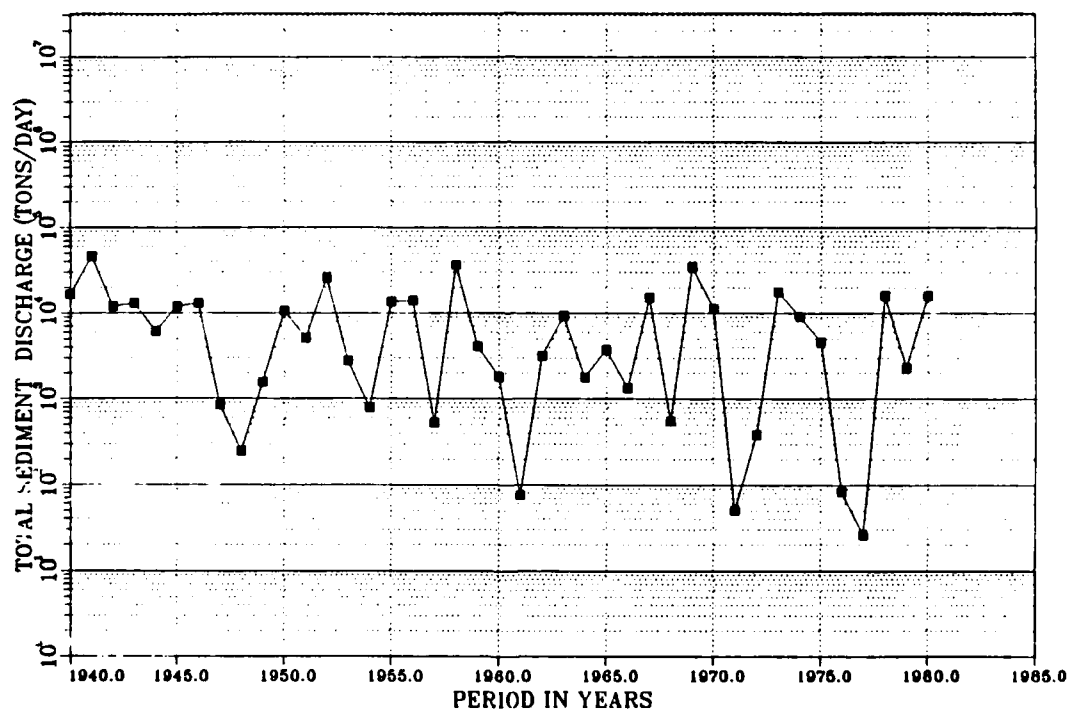
APPENDIX B

COMPUTED AVERAGE SEDIMENT DISCHARGE PER YEAR FOR SALINAS RIVER

SALINAS RIVER 1940-80
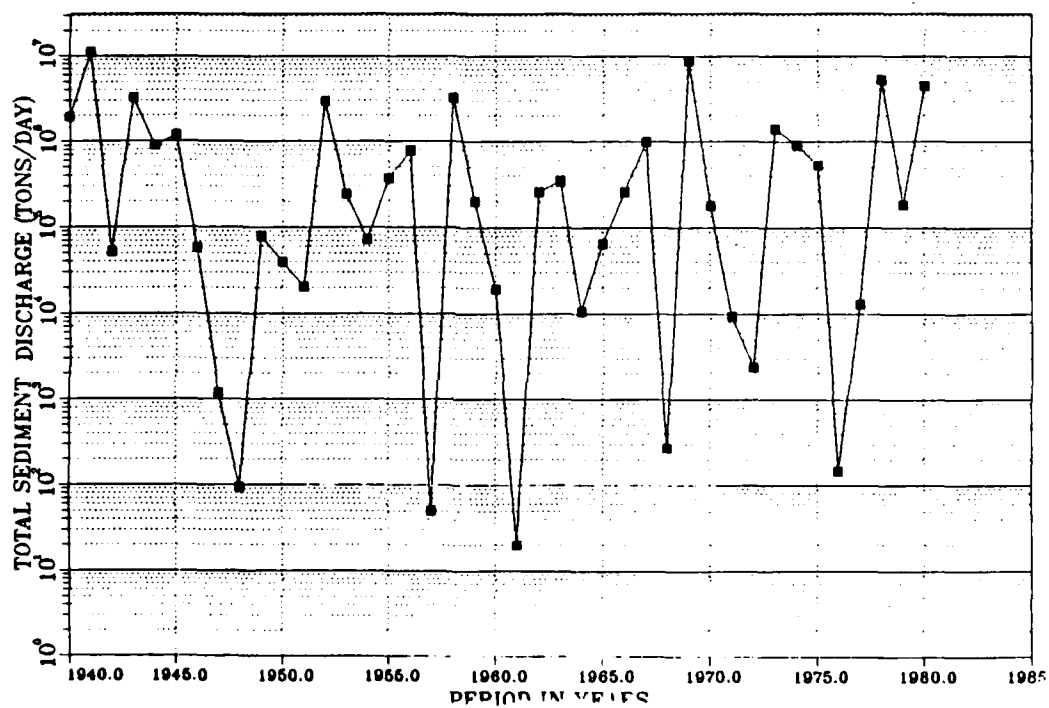
APPENDIX C
COMPUTED AVERAGE SEDIMENT DISCHARGE PER YEAR FOR PAJARO
RIVER

PAJARO RIVER 1940-80

APPENDIX D

WATER DISCHARGE TRANSPORT CURVE FOR SALINAS RIVER
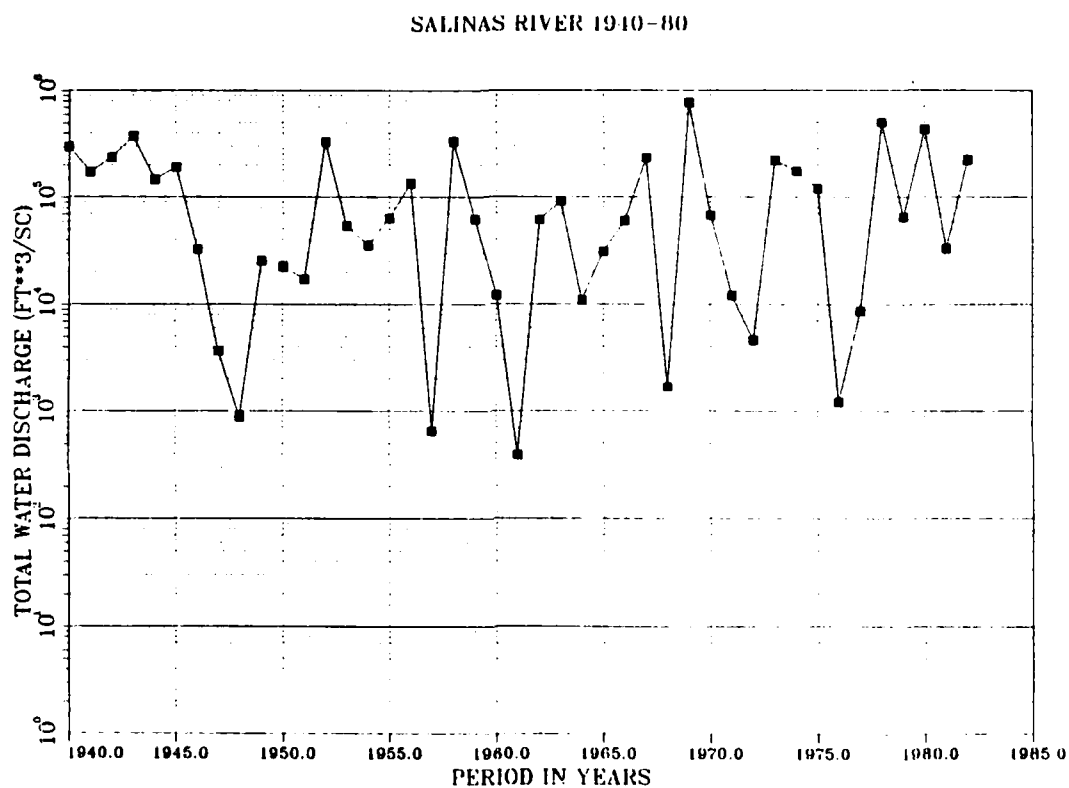
SALINAS RIVER 1940-80

WATER DISCHARGE TRANSPORT CURVE FOR PAJARO RIVER

PAJARO RIVER 1940-80
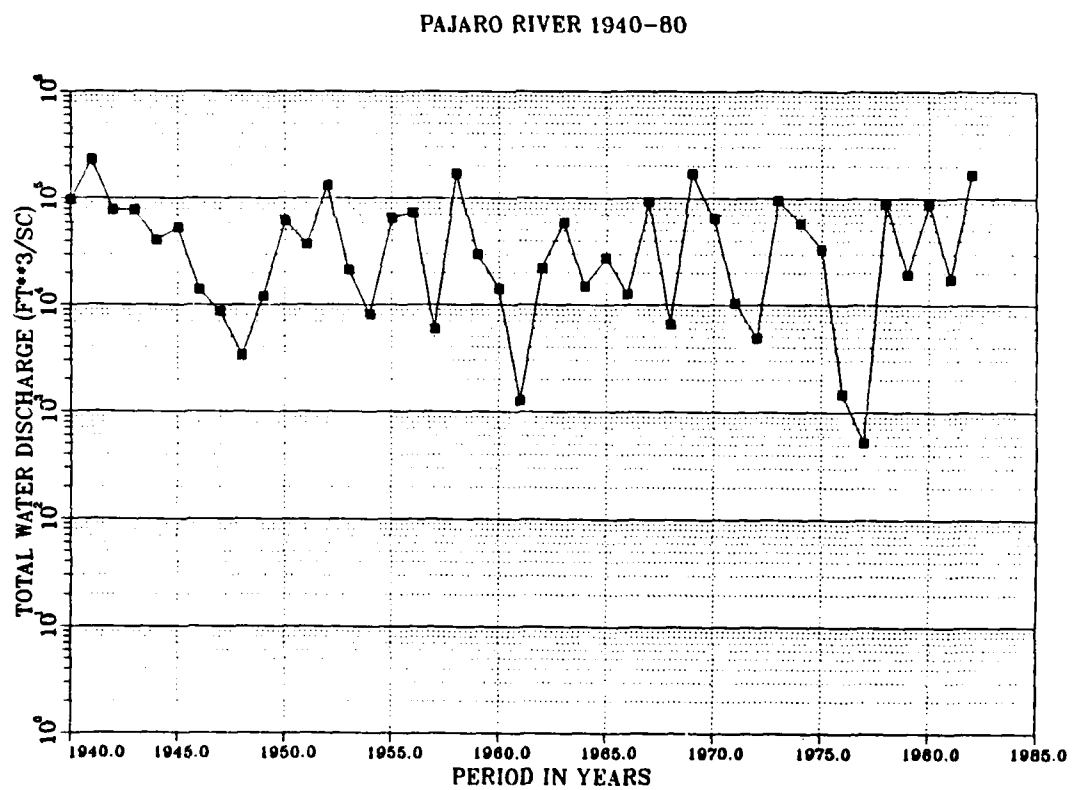
SALINAS RIVER AVERAGE ANNUAL WATER AND SEDIMENT DISCHARGES

SALINAS RIVER
m=1·6369   K=0·0052

1940--1980

PERIOD (IN YEARS)	TOTAL WATER DISCHARGE (CUBIC FEET/SEC)	TOTAL SEDIMENT DISCHARGE (TONS PER DAY)
1940	299989	1936686
1941	172427	11192119
1942	236559	52486
1943	372313	3268696
1944	146361	894451
1945	191413	1192893
1946	32597	58153
1947	3640	1201
1948	883	94
1949	25492	79036
1950	22531	39678
1951	17167	20559
1952	333150	2978528
1953	54465	243981
1954	35667	73041
1955	63769	372220
1956	136008	790624
1957	654	51
1958	337636	3227924
1959	62196	203467
1960	12177	19335
1961	397	20
1962	61470	260299
1963	91941	347984
1964	10908	10671
1965	31024	64844
1966	60297	261620
1967	234303	1010256
1968	1680	272
1969	767628	8768387
1970	67565	179494
1971	12105	9357
1972	4592	2374
1973	222838	1415089
1974	175597	924539
1975	120933	535952
1976	1230	148
1977	8716	13102
1978	501781	5298256
1979	65489	185821
1980	435122	4504332

PAJARO RIVER AVERAGE ANNUAL WATER AND SEDIMENT DISCHARGES

PAJARO RIVER
m=1.2246   K= 0.0018

1940--1980

PERIOD (IN YEARS)	TOTAL WATER DISCHARGE (CUBIC FEET/SEC)	TOTAL SEDIMENT DISCHARGE (TONS PER DAY)
1940	97620	16631
1941	229840	46553
1942	78467	12036
1943	79122	13153
1944	40328	6083
1945	53585	12036
1946	13891	13153
1947	8685	847
1948	3369	249
1949	12046	1559
1950	62701	10688
1951	37089	5104
1952	132757	25959
1953	21300	2803
1954	8126	784
1955	66483	13652
1956	73312	14042
1957	5949	530
1958	171413	36663
1959	29949	4106
1960	14116	1804
1961	1275	76
1962	22043	3173
1963	59441	9415
1964	15000	1791
1965	27926	3799
1966	12514	1331
1967	93479	15332
1968	6582	558
1969	170382	34924
1970	65361	11267
1971	10403	51
1972	4891	388
1973	96891	17624
1974	58931	9180
1975	33528	4655
1976	1494	84
1977	527	26
1978	90359	16041
1979	19216	2316
1980	90813	16080

APPENDIX H

SAN-LORENZO RIVER AVERAGE ANNUAL WATER AND SEDIMENT DISCHARGES

SAN-LORENZO RIVER
$m=2.3747 \qquad K=4.8907^{-6}$

1940--1980

PERIOD (IN YEARS)	TOTAL WATER DISCHARGE (CUBIC FEET/SEC)	TOTAL SEDIMENT DISCHARGE (TONS PER DAY)
1940	96126	658358
1941	133048	760174
1942	75732	190396
1943	56989	123932
1944	26562	13833
1945	52612	113508
1946	22456	6842
1947	13502	1979
1948	16093	1075
1949	30351	59783
1950	61419	29200
1951	49978	146536
1952	99303	560842
1953	37396	69571
1954	34344	15873
1955	60031	13827
1956	54837	595442
1957	60872	6000
1958	96163	350222
1959	30806	244690
1960	18164	9152
1961	9058	792
1962	38828	5590
1963	66093	88000
1964	28736	44075
1965	46704	108468
1966	26383	22091
1967	75797	158253
1968	27739	70736
1969	104672	626503
1970	67989	175894
1971	21397	26704
1972	17036	2457
1973	87322	350528
1974	59986	104470
1975	37002	79993
1976	5951	2923
1977	6621	152
1978	73074	232636
1979	34725	34510
1980	64915	234326

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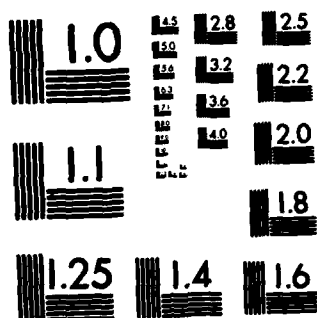
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